ARC WELDING ENGINEERING

and

PRODUCTION CONTROL

This book is produced in full compliance with the government's regulations for conserving paper and other essential materials.

ARC WELDING ENGINEERING AND PRODUCTION CONTROL

BY WALTER J. BROOKING, M.A.
Director of Testing and Research, R. G. LeTourneau, Inc.;
Member, American Welding Society, American Society for Metals, American Society of Tool Engineers

FIRST EDITION

1944
McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON

ARC WELDING ENGINEERING AND PRODUCTION CONTROL

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

Wide acceptance of the arc-welding process for manufacturing modern structures and equipment and the widespread conversion to arc-welded fabrication are evidence that the process is economically sound in modern industry.

In arc welding, there have been much research and highly technical development on the one hand, and on the other a great amassing of shop practice and know-how by individual operators, foremen, and supervisors of organizations making arc-welded products.

One of the great problems in the industry today is to organize and pass on to new key employees a workable knowledge of the shop skill, shop control, and shop know-how, relating arc welding to the fundamentals of modern mass production and scheduling without the new key employee's having to go through years of actual experience to learn all the successive stages in the shop.

Much valuable information is available for the elementary training of operators and the elementary description of the welding process and equipment. This text, dealing with control of arc-welded production, is intended to serve as a link between this elementary literature and the highly technical reports of developmental research, so that the production foreman, the student welding engineer, the learning welding inspector, the organization just converting to welded production, and others newly associated with the industry may quickly and easily obtain a working knowledge of the field.

With that purpose in mind, an effort has been made to present the general factors involved in arc-welded production and the specific means for their control as illustrated by a leading manufacturer in a representative industry, much of the development of which has been dependent upon the arc-welded method of fabrication of the equipment it uses.

No attempt has been made to make the subject matter all-inclusive and completely applicable to all industries. By analyzing the general factors which are operative in a specific

industry (and which occur in the application of arc welding in almost any industry), and by discussing the organization and control of those general factors in detail, the author hopes the reader may be able to recognize the most important factors as they are reflected in any ordinary industrial situation and interpret them in the light of the needs of his particular industry.

The author wishes to acknowledge with gratitude the generosity and cooperativeness of R. G. LeTourneau, Inc., beginning with R. G. LeTourneau, the president, and including the other members of the management and all the shop personnel, in allowing their organization to be used as an example to show to what extent a modern manufacturer may depend upon and effectively use arc welding.

It is also a pleasure for him to acknowledge the generosity of the following publishing companies in allowing him to draw freely upon the illustrations and subject matter of certain of his articles which they have published: *The Welding Engineer* for articles covering flame-cutting, cleaning of welded machinery, electrode comparison tests, material control, the use of welding by equipment serviceman, and the welding engineer's job; *The Iron Age* for articles covering control of fit-up, control of mass-production arc welding, production with alternating-current welding, and machining welded products; *Steel* for articles covering handling equipment, welded machine-tool and power-unit bases, flame-cut parts, jigs and fixtures for welding, and welding inspection; *Mill and Factory* for an article covering welded bins and storage equipment; *Factory Management and Maintenance* for an article covering welded production fixtures and accessory equipment; *The Welding Journal* for an article on the training of welding operators; *Metal Finishing* for an article covering the preparation of welded goods for finishing.

The author also gratefully acknowledges being permitted to draw upon the text and illustrations of an article submitted to the J. F. Lincoln Arc Welding Foundation in 1942 and published in "Studies in Arc Welding."

Grateful recognition is expressed for assistance received from W. J. Connelly and H. M. Downing, engineers of the Lincoln Electric Company, in discussing direct-current welding.

Finally, the author wishes to express his sincere gratitude for the unfailing guidance, counsel, and assistance given to him by

Elmer E. Isgren, plant manager of R. G. LeTourneau, Inc., who read and constructively criticized almost every section of this text.

Without the ingenuity, cooperative efforts, and generous help of all those who have been mentioned (and many others), this project could never have been completed. It is the sincere hope of the author that this result of their combined efforts may make the daily work of others easier, better, or more meaningful.

WALTER J. BROOKING.

PEORIA, ILLINOIS,
November, 1944.

CONTENTS

ARC WELDING ENGINEERING AND PRODUCTION CONTROL

CHAPTER I

ARC WELDING, A MAJOR PRODUCTION METHOD

The arc-welding method of producing machinery and equipment from steel and an ever-increasing number of nonferrous metals and alloys has grown from a casual method of repair a few years ago to a major method of production today. Some of the earliest arc-welding machines were being used about thirty years ago, largely for repair and maintenance work. Today, they are used as the original method of manufacture of large quantities of the machinery and equipment that are so vital to, and so characteristic of, our mechanized society in this age of metals.

This development has been the result of a series of improvements in the materials, machines, and allied processes during the past thirty years to such a point that the facilities now available for arc welding have been demonstrated to embody sufficient economic advantage to cause this method of production to replace to a significant degree the methods used previously.

Arc welding may be defined as a means of causing a localized union or consolidation of metals by fusing them with the heat of an electric arc.

The primary production method here discussed is the metallic-arc-welding process. In it bare or shielded-arc (covered) electrodes have an electric current introduced through them. The current causes the end of the electrode to melt and to be transferred across the arc where it is deposited and fused with the melted metallic surfaces that are being joined by the process. Although the carbon-arc and the hydrogen-arc welding processes are in common use in modern industry, they are covered in this

text secondarily only because of their general similarity to metallic arc welding.

In earliest arc welding done on a commercial basis, bare welding electrodes, or electrodes with only a very thin "washed" or "powdered" surface coating, and a direct-current welding machine were used.

Most of the arc welding that is done today is accomplished by means of shielded-arc electrodes. These electrodes are basically a wire with a covering or coating consisting of materials which form gases around the electric arc that protect the metal

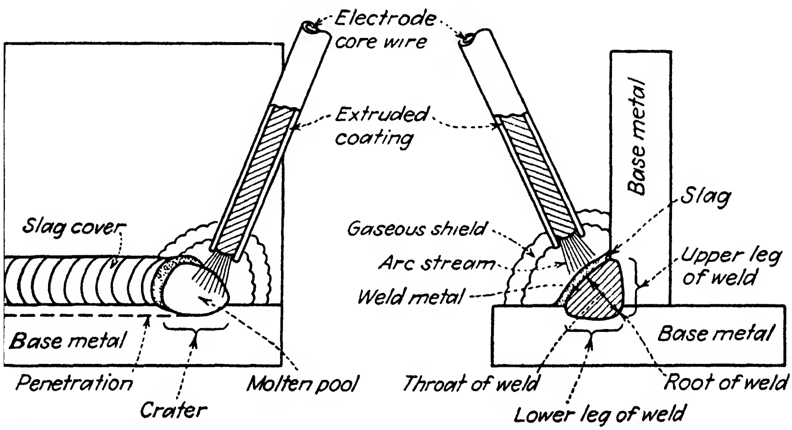


FIG. 1.—An elementary diagram showing the materials and functions involved in making a fillet type joint by arc welding.

from the oxygen and nitrogen of the air, which add alloying materials to the weld metal or scavenge impurities from it, and which deposit a slaglike covering over the metal after it has fused the pieces of parent metal (material being joined) to further protect the metal from the air and beneficially retard its cooling.

Figure 1 is an elementary diagram of arc welding showing the common terms applied to the process, its equipment, and the materials used. The diagram shows a fillet-type joint being fused with a shielded-arc type of electrode.

The shielded-arc process produces greater welding speed and better weld metal in most common welding applications than does the bare wire welding and is, therefore, more widely used.

Metallic arc welding may be accomplished automatically with either bare or shielded-arc electrodes. It may also be accom-

plished by special processes involving the use of powdered fluxes or tapes to protect the weld metal and to control other special factors influencing the welding process.

With the development of the shielded-arc type of electrode, the arc-welding process was freed from certain limitations that were associated with the bare-electrode welding process. By modifying and developing the coatings on the electrodes, either alternating-current or direct-current welding machines were made practical for arc welding. Each has certain advantages and special applications within its own realm and will be discussed in future chapters.

A further development of the shielded-arc type of electrode has been the development of coatings or combinations of coatings and core wire that successfully accomplish the welding of many alloy steels and many nonferrous metals and alloys that could not successfully be welded with bare wire. One example of such a development in alloy welding is that of armor plate, which could not satisfactorily be welded 5 years ago, but which is now welded regularly on a mass-production basis. With such developments, there have been wide fields of commercial opportunity opened for arc welding and an ever-increasing use of the process for the production of modern equipment.

Economic Significance of Arc Welding.—The part that the arc-welding process plays in modern economy cannot be defined in a few words, but there are many indications of its effect. The production of the materials and machines for arc welding and the allied processes has become "big business" in recent years. For example, the total production of steel arc-welding electrodes during 1943 amounted to over 1,080,000,000 lb.[1] This is a significant quantity of material when it is recalled that it is in the form of wire that is practically vaporized by the heat of an electric arc so that it passes across an electric spark and is recondensed. The fused combination of parent metal and electrode thus formed constitutes the means by which the parts of ships, buildings, machines, and other steel products are joined.

The manufacturers of the arc-welding machines that used these electrodes have not uncommonly sold single orders of 100, 500, or upward of 1,000 machines to meet the tremendously expanded need for such equipment. In recent years orders for such num-

[1] Welding, *The Iron Age*, vol. 153, No. 1, p. 114, 1944.

bers of machines compare favorably with quantities of other types of metal-processing equipment, such as machine tools. The gross sales in 1943 of only one large manufacturer of welding electrodes and machines were over $35,000,000.

The development of the equipment for flame cutting of raw steel into the necessary forms and shapes prior to its being welded has also grown to be a large industry. Special flame-cutting and shape-cutting machines have been designed, built, and marketed in large quantities and have greatly increased the efficiency of such cutting operations.

Specialization in the field of arc-welded products has brought about the establishment of individual companies that produce specialized alloy welding electrodes, there being a large enough demand to justify their establishing a business with a reasonable expectation of enlargement and profitable operation.

Related enterprises, such as the production of welding-positioning fixtures, the establishment of welding training schools on a commercial basis, and the building up of welding societies and welding literature, are other marks of the importance of welding.

During the past five years, hundreds of thousands of arc-welding operators have been trained to meet the ever-increasing demand for welded products. Thus welding has become one of the common fields of skilled craftsmanship and a source of sustenance for thousands of modern families.

Variety of Fields of Application.—The number of individual fields in which there has been conversion from other methods of manufacture to the arc-welding method is almost unlimited in the realm of production of steel products.

In addition, a large number of products are now made from steel and other weldable metals because of the special advantages that welded construction presents to designers.

Almost every major category of modern equipment or machinery is represented in the list of products that are welded today. Steel- and metal-producing machines; the equipment and machines used in the petroleum industry, the textile and clothing industry, the printing industry; much household equipment, farming equipment, and fundamental processing equipment are either partly or completely of welded design.

Many of the major functional classes of machinery such as pumps and compressors, prime movers, conveying machinery,

metal-forming and metal-cutting machinery, electrical machinery, and business machinery are of arc-welded design.

At present, many of the instruments of warfare are partly or completely welded. Such major weapons as guns, ammunition, tanks, planes, ships, transportation equipment, and many other tools of warfare are being produced in great quantities for the Second World War.

The automotive industry welds parts or all of some of its assemblies including engines, bodies, frames, and trailers; the aircraft industry welds or partially welds its engines and fuselages; the railroad industry uses arc welding for locomotives, freight cars, passenger cars, locomotive and car parts, tracks, and maintenance equipment. Household furniture and office equipment; containers such as stationary tanks or pipe lines; ships of all kinds such as freighters, tankers, battleships, pleasure craft—all may be partially or completely welded as produced in modern manufacturing practice.

Many modern office buildings, bridges, and public buildings are constructed by arc-welding structural steel for framework and even, in some cases, light steel for the main covering of the structure.

The use of arc welding and some of its newly developed techniques and materials has made possible the design and production of special chemical systems used in the manufacture of synthetic rubber and other chemical products that require the use of tanks, pipes, and special processing units. Some of these must be made of special materials that are not affected by corrosive chemicals and some operate under extreme pressures and temperatures or other conditions that were impossible to control prior to the development of arc-welded construction.

An Example of the Economy of Arc-welded Construction.—An example of a modern product that owes its existence to the excellence of the welded method of production is the earth-moving tractor and grading machine shown in Fig. 2. Both the scraper and the tractor are of arc-welded design and manufacture. The tractor itself is of rather bold and unconventional design since its main frame and transmission pivot over the two large rubber-tire-mounted drive wheels, since it has no front wheels, and since the fuel tanks comprise the motor hanging frame.

The transmission case and frame structures of this tractor frame were originally produced as shown in Fig. 3, being made

up of the transmission case proper, two bolted-on fuel-tank and frame structures, a bottom rock guard, a bumper structure, and a front engine hanger.

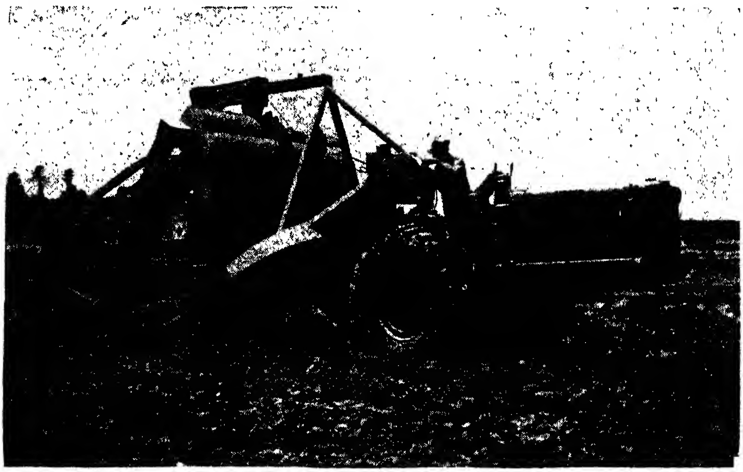


FIG. 2.—An example of modern mass production of arc-welded equipment. These wheel type tractors and earth-moving scrapers are produced in lots of 100 or more per order by specialized workmen on modern manufacturing and assembly lines. (*Courtesy of R. G. LeTourneau, Inc.*)

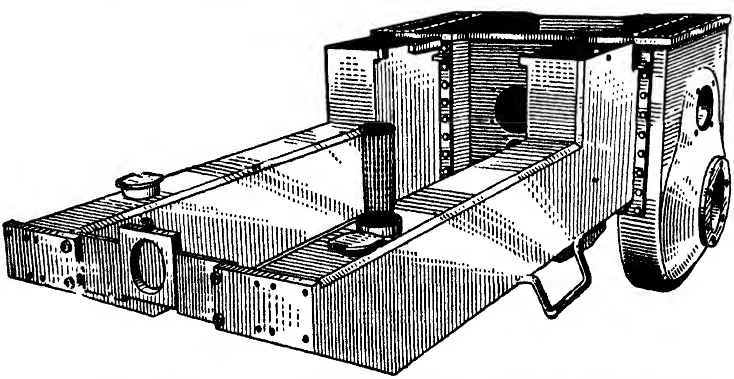


FIG. 3.—The original welded tractor transmission case with its "bolted-on" welded fuel tanks and motor hanger. (*Courtesy of R. G. LeTourneau, Inc.*)

This construction made good use of arc-welding design, and careful analysis of its cost[1] showed that it was 41.6 per cent less

[1] BROOKING, WALTER J., Tractor Transmission Case and Frame Assembly, in "Studies in Arc Welding," pp. 1022–1079, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, 1943.

expensive than the only other method by which it could have been made; that of using steel castings.

After a sufficient number of these machines had been produced to prove the design, certain additional advantages were obvious that could be attained by further using arc welding to simplify the design of this assembly.

These changes were made and resulted in the transmission and frame structure shown in Fig. 4. Chief among the changes were the welding of the fuel tanks to the main transmission case, which eliminated the machining, the bolts, the nuts, and the

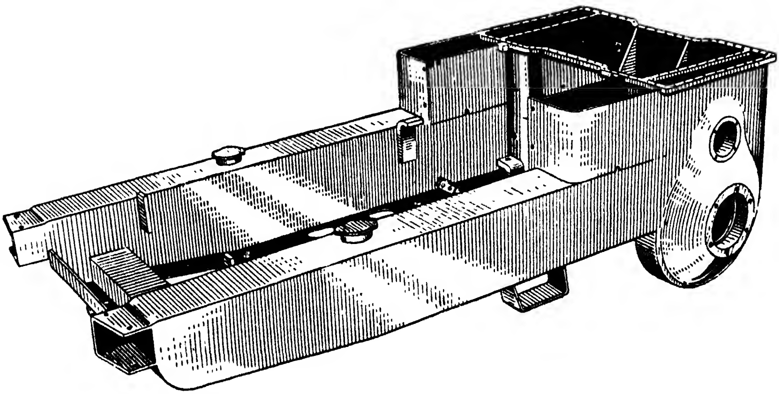


FIG. 4.—The improved welded tractor transmission case with its welded-on fuel tanks, belly guard, motor-hanger lugs, and generally more rigid design. The cost of this case and frame assembly was almost $50 less than the original arc-welded design. (*Courtesy of R. G. LeTourneau, Inc.*)

bolting process and made possible a more rigid and more streamlined case and frame structure.

The new design reduced the original manufacturing and assembling cost for the frame and case structures by 13.8 per cent, a step that allowed a 55 per cent increase in the net profit based on the same selling price as the original unit.

Figure 5 graphically shows the significance of the profit resulting from this improved design. The established product in the field was redesigned and made for 13.8 per cent less cost, was made superior to the original product, and sold for the same price, allowing the manufacturer a margin of 55 per cent more profit than he realized on the original design (assuming a 20 per cent profit on the original design). The most important factor in

this situation was that almost all the savings realized by improving the design were transferred immediately to the profit side

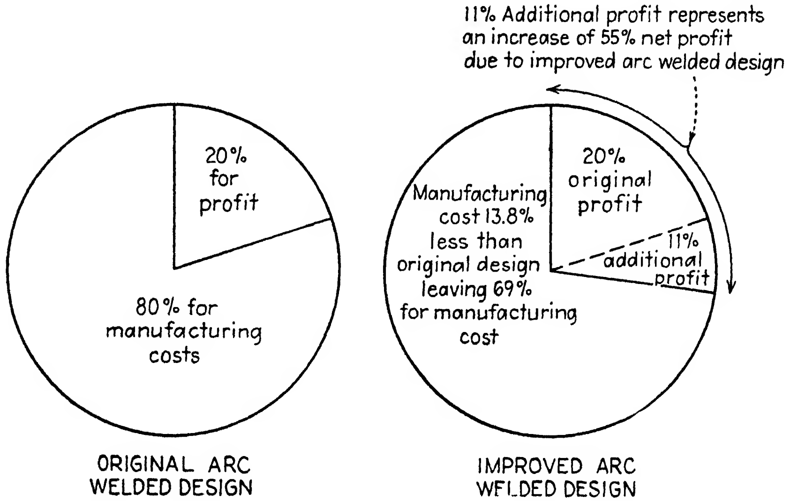


FIG. 5.—The economic importance of simplifying and improving even a good welded design, based on the units shown in Figs. 2 to 4.

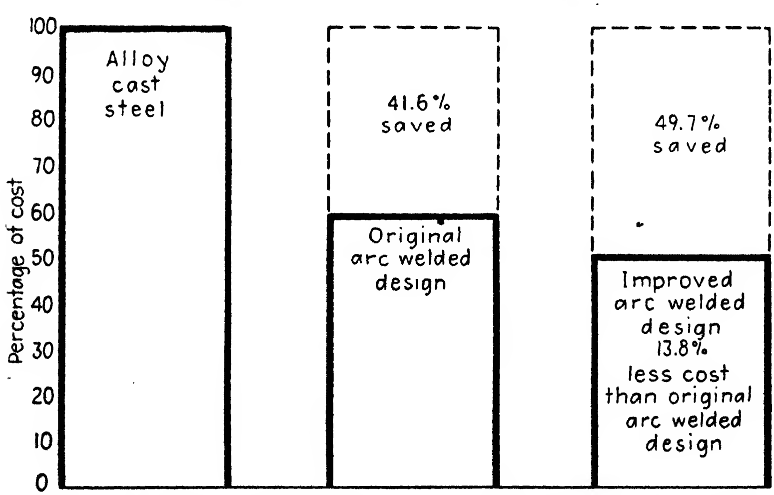


FIG. 6.—A graphic means of showing the relationship of the cost of production of the tractor transmission case and frame assembly as steel castings, by the original arc-welded design, and by the improved arc-welded design.

of the ledger without being charged to sales expense or the other industrial costs that had to be included in the price of the original

arc-welded product. Figure 6 demonstrates the relationship of the cost of the original arc-welded design and the cost of a comparable unit made by a method other than arc-welding; it also shows the relationship between the cost of the improved arc-welded design and the cost of the original.

It is the realization of economies and profits in manufacture such as this which has caused the conversion of many producers of steel products to the arc-welding design and method of production.

Methods of Conversion to the Arc-welding Process by Modern Manufacturers.—The speed and manner of conversion from other methods of manufacture of equipment such as the use of cast iron, cast steel, or riveted structural steel to arc-welded design and manufacture have been different in different organizations.

In some cases, the organization's acquaintance with arc welding was made as a means of repair and maintenance within the manufacturing plant. Certain inherent advantages of the welding process became apparent, and a change-over to welded design was undertaken gradually, first, by incorporating welded parts or simple welded structures into the product and, finally, by producing completely welded units. This change has occasionally been drastic to the extent of burning all the old patterns for cast-iron production and simply embarking upon the arc-welded design immediately.

In some organizations, the designing and welding of a few shop fixtures have given experience in welded design and demonstrated its superiority as a method of production.

In other cases, items of equipment were required that could not be built by any other method; so the arc-welded design was the only practical means of production.

In some other cases, a portion of a machine (*e.g.*, the frames of automobiles) was partially welded and gradually a larger and larger percentage of the unit was converted to the arc-welded construction.

Many organizations have become arc-welding manufacturers because of having accepted contracts for military equipment of welded design and have plunged into the problems and processes of welding where the designs were already perfected and it was simply a case of learning the know-how of welding production.

Many organizations have become arc-welding manufacturers because of the production of some arc-welded unit that was so much better than existing equipment that the demand for the welded units quickly outmoded the older types of machine. The production of much of modern earth-moving equipment is an example of this type of development.

Arc-welded Design Is Simple and Practical.—The use of the process for manufacturing machinery or equipment from steel has attained much popularity because of its simplicity and because of the fact that a large investment in material and equipment is not necessary to produce salable goods.

The fact that a modern mechanic who can use an arc-welding machine and a flame-cutting outfit can produce equipment or machinery from steel shapes, plates, and bars in the same way that a skilled cabinetmaker or carpenter would produce them from lumber constitutes one of the great advantages of arc welding. It places the means of efficient production of experimental units in the hands of the ordinary mechanic so that the natural ingenuity of the average skilled craftsman can be reflected in the production of equipment that solves the problems he meets in his daily life.

The fact that parts of machines may easily be made by flame cutting them to the proper shape and size and that the edges of the parts may be fused rigidly and continuously without the need of a large amount of expensive or complicated processing machinery is a great advantage of the arc-welded method of production.

It is also an advantage that the units may be made liquid- or gastight if necessary. For this reason, welding is unexcelled as a means of producing many storage, conveying, or processing units for liquids or gases.

The welding process is one of joining edges in a manner that produces joints as strong as the parent metal and therefore eliminates great quantities of material used for overlapping or for actual joining as in the case of riveted structures. It also reduces the amount of bracing and stiffening units required by some types of construction, such as riveting or bolting. A similar reduction in material is accomplished by welding where it reduces or eliminates reinforcements or fillets common to cast-iron or steel construction.

Another advantage is the fact that the inherent strength of steel per unit of weight and volume has tremendous advantages over cast iron or wood for certain designs; therefore, it has become much more popular for the production of many types of equipment.

The modern developments in the arc welding of aluminum and other metals and alloys further widen the horizon for arc welding of a large variety of equipment.

Arc Welding and Mass Production.—As a means of producing equipment on a mass-production basis, arc welding has been demonstrated to be very economical. The fundamental materials, steel and electrodes, are both relatively inexpensive. The great majority of the steel that is used in arc-welded construction is hot-rolled plates, shapes, or bars which may be welded as they are received from the steel mill after they have been cut, bent, shaped, or formed to the proper dimensions. After the parts are cut, they are set together and are fused into parts, substructures, then final structures; after which they may be taken to assembly lines and assembled.

All these operations may be divided and subdivided and departmentalized in such a way as to form a modern line of production with its subdivisions of work and directional flow of materials, all correlated to a controlled production.

Elasticity of the means by which many operations prior to the welding operation may be done makes expansion of welded production from a workshop to a factory a relatively easy process. Such an expansion obviously includes the problems of space, manpower, and equipment that would be involved in any other production expansion; but the wide variety of means of accomplishing the steps of cutting, forming, shaping, and setting up of structures by means of laborsaving fixtures and the ease with which welding operators may be trained are in favor of the welding process.

Need for Production Engineering and Control.—With the growth of the arc-welding process to its present importance as a production method, there has developed a great need for an easy means of getting a working knowledge of the fundamental problems and factors which are involved in the method and which must be controlled for economical production of goods.

Any process that becomes widely used for the production of modern equipment and machinery must be subject to such engineering control and planning and should be relatively simple. This is true of arc welding.

The primary objective of the following chapters is to present an analysis of the major factors, problems, and processes in the arc welding of equipment on a production basis so that the understanding required for production planning and engineering control may be more easily and quickly acquired by the beginning producer in the arc-welding field or by the production engineer, time-study man, cost accountant, foreman, or student of welding production.

In the next chapter, the major problems and factors are described, qualified, and discussed in general. Later chapters are devoted to a more complete analysis and discussion of the significance and the means of accomplishing a practical engineering control of these factors and problems.

CHAPTER II

PROBLEMS AND FACTORS IN ARC-WELDING PRODUCTION AND CONTROL

The solution of the problems involved in arc-welded manufacturing of equipment and the control of the factors involved are popularly considered to be the work of some individual called the "welding engineer" in a welding organization.

Since all these problems and details in even a relatively small organization are beyond the scope of one man, and since the factors and problems involve all the phases of welding production from designing through production planning, production control, processing, actual workmanship, and inspection, the discussion of the problems of welding engineering might better be approached by a general analysis.

By scientific, objective study and evaluation of the elements of a manufacturing situation a method may be selected that presents an economic margin over other available choices or processes, either in cost or quality of product.

Many of the problems encountered in a manufacturing organization, such as the one that produces on a mass-production basis the heavy earth-moving equipment unit shown in Fig. 2, are somewhat different from those found by the manufacturer of airplane fuselages or of ships; and the problems of any of these mass-production shops are naturally somewhat different from those of the organization which operates as a large job shop, producing special machinery built to special order.

However, mass-production manufacturers of welded equipment encounter many of the same problems as the specialized job shop if they build special shop machinery or fixtures such as the special flame-cutting machine shown in Fig. 7. The designing, engineering, and manufacture of these special shop units bring about problems which are, in many respects, similar to those of the large job shop.

A general analysis of the operations and functions that must be performed in the production of welded equipment, either on a

mass-production scale or on the job-shop operation scale, will tend to illustrate the welding-engineering functions that someone in the organization should know and should be able to perform. It should be borne in mind continually that the fields of operation are described not as the work that one man should do, but rather as the functions that have to be done.

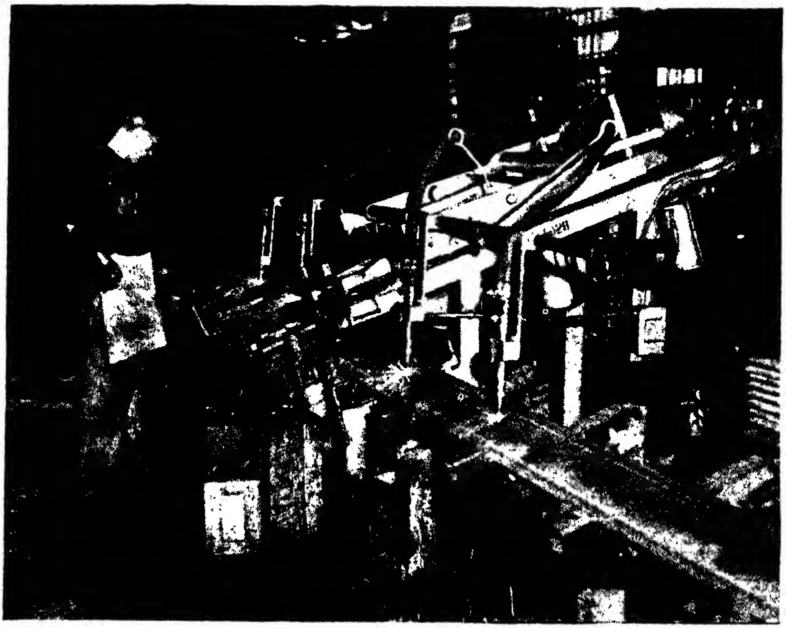


FIG. 7.—Mass producers of arc-welded products have many typical "job-shop" problems if they build their own special equipment such as this automatic flame-cutting unit. This unit was designed and built to cut special cutter-blade sections from rolled stock. (*Courtesy of R. G. LeTourneau,* Inc.)

With this in mind, the following is a list of general operations and problems of organization that must be dealt with in arc-welded production.

1. Evaluate and select welding processes, machines, and equipment.

2. Evaluate and select appropriate welding electrodes for all processing done in the plant.

3. Examine and evaluate welding operators seeking employment.

4. Train and adapt welding operators to the company's special processes.

5. Correlate welding design with practical shop practice and available shop equipment.

6. Create production fixtures for welding (setting up and positioning for welding).

7. Establish the general procedures for welding the company's products.

8. Establish production control of procedures in detail.

9. Establish quality control (inspection).

10. Keep informed on practices and processes in the industry so as to keep the company's processing up to date.

To select any portion of this group and establish it as the special work of one person called a welding engineer and to apply that particular selection of duties to the profession of welding engineer for all organizations would be completely impossible. However, the function served by a welding engineer in an organization will certainly include some of the 10 general fields, and perhaps a portion of all of them will be integrated with other departments and persons in the organization.

With this in mind as the major part of the total welding-engineering job in an arc-welding organization, an analysis of the duties involved in each of the 10 groups will now be undertaken.

Evaluating and Selecting Welding Processes, Machines, and Equipment.—Once an organization has committed itself to the production of arc-welded goods, there are still problems to be solved as to what type of welding machine and equipment should be used.

The question as to whether alternating- or direct-current machines should be purchased for the company's product is strictly a welding-engineering problem. Someone in the organization must know or find out, on the basis of a study of material, power, type of welded product, and all other important influencing factors, whether the use of alternating current from a transformer-type welding machine (such as is used by the welding operator in Fig. 8 for the mass production of a part of a heavy earth-moving machine) or of direct current from a motor-generator type welding machine is more practical for the series of operations under consideration.

The question as to whether parts of the manufacturing process might better be done by automatic welding or by manual welding is also a welding-engineering problem.

After the decision as to the type of machine to be used has been made, the selection of the particular machine to be used in the plant or the best machine to replace such machines as are already in the plant when they become obsolete is another problem of welding engineering.

The determination of the size (or capacity) of the machine is also a decision which should be made, considering the type of work that is going to be done and the variety of work that the

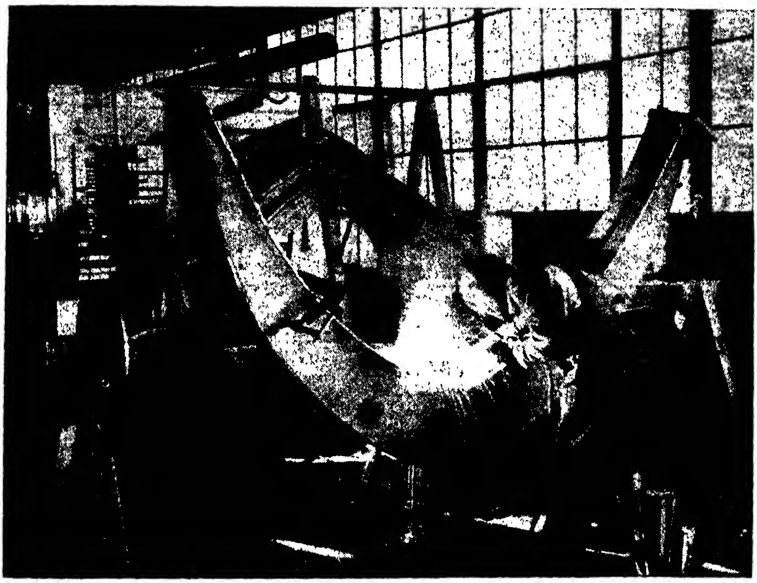


FIG. 8.—The selection of the best type of welding equipment for this type of mass-production job is a problem in welding engineering. (*Courtesy of R. G. LeTourneau, Inc.*)

machine will have to do, with special attention to the size and type of electrodes and relative continuity of use (50 min. per hr. for 24 hr. a day or 30 min. per hr. for shorter hours per day).

The man who makes comparative tests and evaluates machines within a given group (alternating-current transformer, direct-current motor generator, or automatic welding units) need not necessarily be a full-fledged electrical engineer, although certain considerations of power consumption, fundamental efficiency, and equipment investment require an analysis that is of a technical nature.

The actual comparison of machines on the basis of operation, operating characteristics, over-all efficiency, and probable satisfactory service may best be accomplished by objective comparative tests, plus examinations of the machines from the mechanical standpoint.

Such tests should always include actual deposition tests in which a certain number of electrodes or quantity of welding is done under controlled conditions. Whenever possible, they

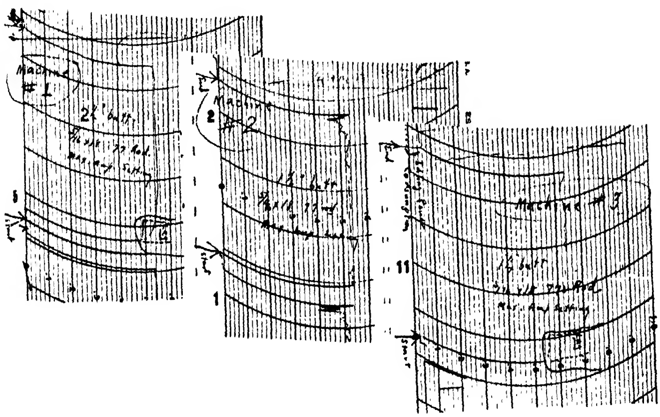


FIG. 9.—Automatic recording equipment for testing welding machines or electrodes provides the welding engineer with valuable data. Note the difference between machine No. 2 and machines No. 1 and No. 3 as shown by the recording kilowatt meter which indicates that machine No. 2 rises immediately to full welding current delivery after striking the arc, while No. 1 and No. 3 lag in output for several seconds.

should also include careful over-all consumption studies using a recording kilowatt meter, or some other means of determining the amount of power used, and the amount of time (labor) required to do a certain job of deposition of metal.

Such tests should also include a study of the extremes in setting and operating of the machines so that the lowest amperage possible is obtained, and therefore the smallest electrode usable, as well as a study of the reactions of the machine at very high settings.

Another thing that the recording kilowatt meter may be used to describe is the speed with which a welding machine may be

brought to its welding efficiency after the arc has been struck. Figure 9 shows such a recording of the arc-striking characteristics of three separate machines and demonstrates a very noticeable difference between them.

Other equipment besides welding machines must be selected and evaluated, *e.g.*, hoods, cover glasses, electrode holders, cables, cleaning brushes, and slugging tools.

Methods of grounding welding machines, the installation of the grounds, and the arrangement of machines in the factory for efficient welding are related problems requiring study. These are all problems that offer a variety of solutions, and someone in the organization (whether he is called the welding engineer or something else) should be able to conduct objective tests and arrive at an answer that can be demonstrated to be the best.

Evaluating and Selecting Welding Electrodes.—Since welding electrodes are a fundamental raw material of the arc-welding process and since the weld metal deposited in the welding process becomes an integral part of the product, careful study and evaluation of welding electrodes present a very important field for objective and detailed study. A complete discussion of this subject in this review of welding-engineering factors is impossible, but there are certain major considerations about electrode selections that are of considerable importance on any job.

One of these is that the electrodes must be selected for the type of material being welded upon and must operate to the best advantage with the welding equipment and the skill of the welding operators that are available in the organization.

For ordinary steel-welding operations on a mass-production basis, there are sometimes special physical requirements that must be met by the electrodes and the welding process. These may be tested by control agencies outside the organization, but someone in the organization must understand the fundamentals of the selection and testing of welding electrodes as a part of the use of the welding process for production.

Another major consideration in welding-electrode selection is that of using the electrode best adapted to the common positions in which welding is done in the plant, *e.g.*, AWS class E 6020 type electrode (for ordinary low-carbon steel) for down-hand welding and E 6010 or E 6012 electrodes for horizontal, vertical, or

overhead welding, in order to deposit the weld metal most economically.

Special types of electrodes, such as hard-surfacing or high-tensile electrodes in the manufacture of equipment or in the maintenance of regular manufacturing machinery, should be studied in the interest of obtaining the greatest possible economy from the arc-welding process.

Fig. 10.—Regularly run and carefully controlled (stop watch, rule, ammeter, and weighing balance) electrode comparison tests are a source of economic margins for manufacturers of arc-welded products. (*Courtesy of R. G. LeTourneau, Inc.*)

Comparative tests of electrodes within a certain type, such as comparing the E 6010 electrodes produced by various companies as applied to the special welding problems of the organization, constitute another effective source of economy if approached from the engineering standpoint—that of controlled scientific measurements and tests (see Fig. 10).

This phase of the welding engineering in an organization is not one which can be done once and then forgotten about, but is one which requires periodic reexamination and testing in order to give assurance that the best practice is at all times being followed and that the electrodes best adapted to a particular type of production are being used.

in a way that gives assistance to the new man when he needs it, but that might not be possible if it were left to the departmental supervisor on the job.

Another good investment in this type of education is the special emphasis on safety in the handling of electrodes and machines in such a way as to reduce the possibility of damage to machines and equipment during their operation or during the hours when they are not being used. A welding machine, if left turned on and grounded by the lead, is likely to become overheated and damage (or even destroy) the machine or other parts of the equipment. This phase of education is important and lends itself profitably to the orderly and scientific approach of the engineering method.

Correlating Design with Practical Shop Practice and Equipment.—While there sometimes seems to be a tendency to assume that the function of designing welded equipment should be a prerogative of the engineering department alone, there are certain instances in which it is advantageous if the common knowledge and the principles within several departments of the organization be pooled.

A pooling of the knowledge of the capacities of machines in the plant often leads to a better original design or a more efficient processing of parts for welded structures. For example, shears for cutting parts from the plates, the over-all capacity of flame-cutting units, the capacity of bending brakes, rolls, or presses are important items in the production of parts for welding and have a distinct bearing upon certain details of design.

The relationship of volume of weld metal to increase in lineal dimensions of weld, as shown in Fig. 12, is also a principle that should be shared alike by the manufacturing part of the organization and the designing engineers. This is distinctly a phase of welding engineering that is significant in both welding design and welding-production practice. It often may be important to know that it is possible to weld two thin pieces of steel into a structure in such a way that their total strength equals that of one piece whose thickness equals that of the two thin pieces, yet the two thin pieces require only one-half as much weld metal to fuse them into the structure as the single piece (see Fig. 12).

It may be that machinery is available that can process the plates equal to half the total strength required but that cannot

process a solid plate equal to the total strength required. It also may be that the additional work involved in making two of the thinner pieces will cost less than the deposition of the double quantity of weld metal required for the single thick piece.

Using a bending brake (see Fig. 13) whenever possible in the production of welded structures instead of putting two pieces

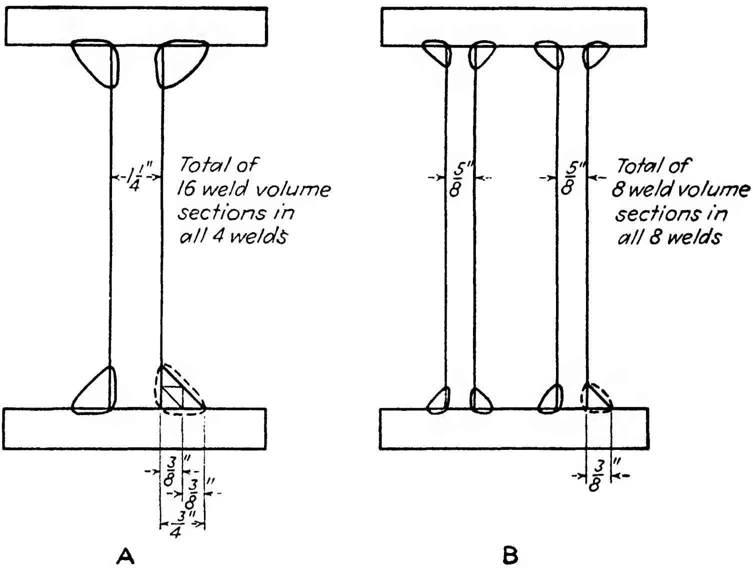


FIG. 12.—Fundamentals of welding design, especially a knowledge of relative strength of welds, should be widely known in a welding organization. In this case, the total web sections in A and B are equal in strength, but only one-half the weld metal (and time and cost of welding) is used to fuse the total web section in B as required in A, each welded to a comparable strength.

together and welding them is another general principle that may often result in simplification of design in the manufacture of the first one or two experimental units before they have been standardized for mass production. Such simplifications of design early in the production of a unit can almost always be depended upon to produce real economy in mass production of the unit.

Other fundamental considerations in the engineering of welding design are the determination and control of the correct amount of welding on certain types of joints. On some kinds of welded units, as much as 90 per cent of the joints are of the T, or fillet, type, where the legs of the weld may easily exceed the thickness

of the plate to almost any degree to which the operator wishes to deposit metal.

Increases in the size of the weld on T-type joints result in increases in volume of weld metal (and cost) by the square rather than by the lineal dimensions as shown in Fig. 12, so that if the size of a weld is increased only one-half its normal size, over twice the amount of time, power, and weld metal are required to weld the joint.

FIG. 13.—The use of machines such as this bending brake to reduce the total amount of welding on an arc-welded unit is another important phase of welding engineering. (*Courtesy of R. G. LeTourneau, Inc.*)

The knowledge of these fundamentals on the part of the organization in general leads to more economical welding engineering at the beginning of the design and construction of a new unit. Whenever a design can be made to cost less or a change can be made to reduce the cost of welding without reduction in quality or strength of the unit, it is a good piece of engineering.

The weldability of different materials that may be included in design and the relationship of the welding process to the chemistry and metallurgical properties of the materials in the structure are also problems that not only affect the original design of the structure, but also involve the members of the organization who

are engaged in cutting, shaping, heat-treating, machining, and other processing of the product.

All these factors are parts of the general subject of welding engineering, and all must be considered in some degree by the producers of welded goods.

Create Fixtures for Setting Up and Positioning for Welding.—Each welded structure should be studied individually with the

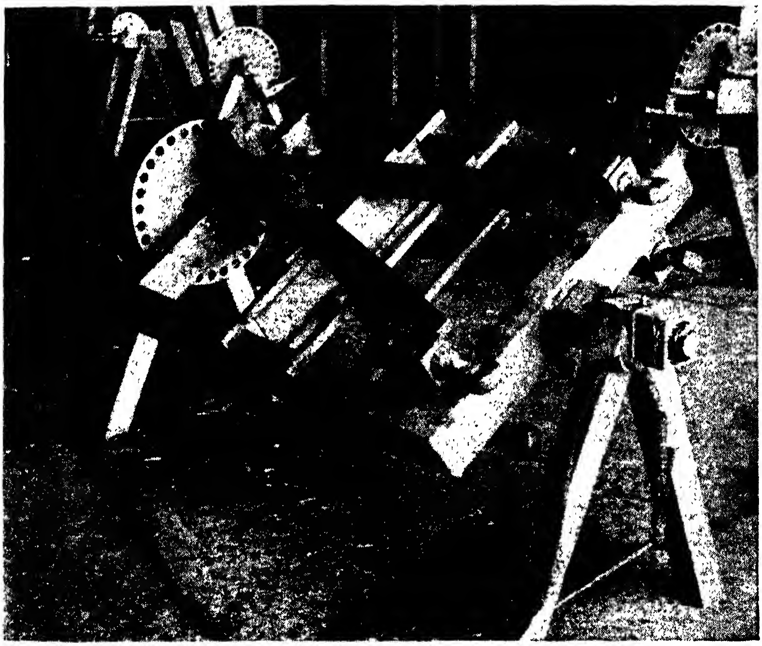


FIG. 14.—Building fixtures that speed up, standardize, and simplify setting-up and welding operations is an important welding engineering function that offers real sources of economy. (Note the use of premachined parts in this structure, and their protection from weld spatter drops by the fixture.) (*Courtesy of R. G. LeTourneau, Inc.*)

object of setting the parts together more quickly, positively, and efficiently and of positioning the unit for welding as favorably as possible to reduce the total cost of its production. This study also includes the possibility of premachining the parts prior to setting them together and welding them, as shown in Fig. 14, as a phase of welding engineering which is often lucrative.

The effect of the heat of welding and the resultant distortion and locked-up stresses are also a part of the study of the structure and designing of the most efficient fixtures for its production.

Often structures may be made into several substructures in order to achieve more favorable positioning during the welding process (a larger percentage of the welding being done in the down-hand position) or in order to reduce the handling and increase the ease of machining certain parts that cannot be totally premachined.

The use of time-study methods to establish the differences in cost between down-hand welding and horizontal-fillet welding or between fillet welding and vertical welding or overhead welding in a particular organization is one of the best means of establishing the amount of added efficiency that can be achieved by positioning welds for down-hand or for more favorable welding during their manufacture. It is commonly found that a reduction in time and cost of welding of 25 to 50 per cent can be achieved by the production of a fixture for positioning of welds, where some welds have to be deposited in the vertical or overhead position and can be positioned for deposition in the flat or horizontal-fillet position.

Establish Procedures for Welding the Company's Products.—After the jigs and fixtures have been built, a general stepwise procedure for the setting up and welding of structures naturally follows.

When the product is made on a mass-production basis, stepwise check sheets such as shown in Fig. 15 should be made up giving the individual steps one after another and including the setting up of the parts and the stepwise deposition of the welds in the proper sequence so as to minimize or control the effect of distortion from the heat of welding. These check sheets in the hands of the operator give an engineered set of specifications that answer his questions such as, "Which part shall I set up first?" and "Which welds shall I make, and in what order?" in a way that allows for standardizing of operations and the resultant standardization of products.

In the production of an individual machine or only a few machines, this type of planning must of necessity be done. Likely it will be done by the special setup man who is building the unit, or it may be accomplished by special notes on the print from which the setup man works.

In mass-production operations, or in single-unit production, unless there is a stepwise planning of the production of the unit,

	Elements				
1	Check in parts				
2	Turn, pos. bk. plts. in jig, tack & weld seam				
3	Pos. & tack top curved plate				
4	Pos. & tack bot. curved plate				
5	Pos. & tack frt. plates, tack & weld seam 1st pass				
6	Turn W. frt. plates to top curved plt.				
7	Turn, W. frt. plates to bot. curved plate				
8	Turn, W. bk. plates to top curved plt.				
9	Turn, W. bk. plates to bot. curved plt.				
10	Turn, bolt shv. jig to main jig				
11	Pos. & tack apron shv. & single shv.				
12	Remove shv. jig				
13	Pos. & tack spacer plt., W. apron shv. to frt. plt. lt. side				
14	Pos. tack & weld gusset to spacer, pos. & tack to A frame				
15	W. single shv. & gusset to frt. plt. (outs.)				
16	W. gusset, spacer & apron shv. to frt. plt. (ins.)				
17	W. apron shv. (outs. rt.), spacer & sgle. shv. ins. to frt. plt.				
18	Pos., tack, & weld rt. tailgate shv.				
19	Pos. tack & weld brace to tailgate shv. & frt. plt.				
20	Pos. tack & weld lt. tailgate shv.				
21	Pos. tack & weld brace to tailgate shv. & frt. plt.				
22	Turn, W. side of tailgate shvs. to back plates				
23	Turn, W. shv. braces to top plt. (1st side)				
24	W. spacer plates to apron shv. & sgle. shv. (ins.)				
25	Turn, W. shv. braces to top plt. (2nd side)				
26	W. apron shv. to top plt., rt. spacer to apron shv. & top plt. (outs.)				
27	W. lt. spacer to single shv., apron shv. & top plt. (outs.)				
28	W. apron shv. (ins.) to top plt.				
29	Turn, W. 2nd pass on frt. plt. seam				
30	Turn, remove structure to floor				
31	W. seams, frt. plts. ins., back plts. (outs.)				
32	W. tailgate shvs. to back plates				
33	Aside str., paint no., pos. card.				
		Total			
		Job No.			
	Date__________ Scraper department F 8016 LS "A" frame Setup and weld	Unit No.			

Fig. 15.—The establishment of an orderly sequence of operations in the production of welded structures must precede their standardization and most economical mass production. This check sheet gives the sequence of operations for the structure shown in Fig. 8. (*Courtesy of R. G. LeTourneau, Inc.*)

the fixtures that may be available for the use in the production of the substructures or structures that go into the unit may not be used to best advantage, and the maximum efficiency that should be developed from having such fixtures will not be realized. This is an important part of welding engineering from the standpoint of economy and in the interest of controlled appearance and standardized products.

Organize Detailed Welding Control.—There are certain phases of detailed control of the welding process that, unless prescribed as written specifications, are likely to cause variance in processing which will be reflected in variations in appearance of the finished product, lack of interchangeability of parts, and also variation in the cost of its production. This is especially true in the mass production of welded products, although some of the specified information must be presented on even solitary-unit production.

The details that should be specified comprise the answers to the questions that the welding operator should ask, and have answered in his mind, before he strikes an arc on the structure. They are briefly as follows:

1. Where should this structure be welded?
2. What size of weld should be deposited?
3. What is the cross-sectional view or form of this weld when it is finished?
4. In what position should this joint be welded?
5. How many passes (layers) of weld metal should be deposited to make this weld according to best procedure?
6. What type of electrode should be used for the deposition of each layer of weld metal?
7. What size of electrode should be used for the deposition of each layer of weld metal?
8. What machine setting should be used for each separate pass?

The answers to these questions may in part or all be placed on the blueprint of the structure by the use of welding symbols like those shown in Fig. 16.

In the manufacture of a single machine or a very small number of machines, welding symbols are sometimes used only on the major parts of the machine. The craftsman who sets up and welds the unit may be a more skilled workman from the standpoint of welding engineering than is the man who might normally

be doing the work on comparable units in mass production. He may therefore be more capable of deciding the answers to some of the welding problems than is the workman who repeatedly does the same operation or series of operations, but does not do the whole job.

In whatever manner this information is imparted, it is engineering work, and it is a field of engineering in welding that presents opportunities of control and economy on a considerable scale, especially on a mass-production operation.

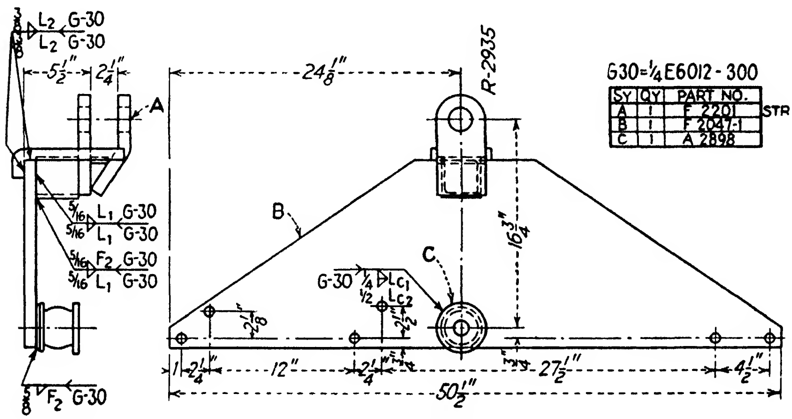


FIG. 16.—Arc-welding symbols used as shown on this print form a practical means of conveying engineering information in exact and complete detail to the welding operator, welding foreman, and welding inspector. (*Courtesy of R. G. LeTourneau, Inc.*)

The establishment of a system for such a control (welding symbols on the blueprints) requires a certain amount of education on the part of the operator in order that the information may be understood and properly followed. This educational work is a phase of welding-operator training that can be standardized by the use of the American Welding Society welding symbols, which are widely used, but it also requires individual plant adaptation and training.

If this phase of the welding engineering has been accomplished, the degree of control, cost analysis, cost prediction, and work scheduling that is necessary for a really successful manufacturing process can be accurately maintained.

Further, with this information in hand it is not at all impossible to establish, on the basis of time studies, standard times for the

setting up and welding of structures that can be used on a "production" basis, using an incentive system that allows the operator to capitalize on his own skill, efficiency, and workmanship as commonly established and practiced under such systems.

One additional step must be taken in order to make such a system a success with arc welding, and that is a continual detailed study of the fit-up of the parts on each structure and a crusade to keep them to a standard that is normal for the structures and therefore reflected consistently in the standardized time set for the completion of any given job.

Establish Quality Control (Inspection).—The problem of quality control in arc-welded products is one that must be solved for each individual organization and each individual product.

If there are complete specifications as to size, appearance, and quality of weld, a large portion of the engineering has been done, because the process of quality control resolves itself only into determining that the specifications are met.

Whether there are complete specifications or not, welding-quality inspection is called for on any welding job. Someone in the organization must be responsible for either periodic or 100 per cent checking of the welding operator's work to control the degree of perfection of the finished product.

Inspection of welded products may be a very highly specialized process, involving special techniques prescribed by code and requiring apparatus and skilled technicians for its accomplishment, or it may be a simple visual examination of the work. The X-ray, gamma-ray, magnetic-flux, and other special nondestructive inspection methods used on pressure vessels, military equipment, and several other applications require a greater degree of specialized training on the part of inspectors than does the simple guided-bend test or other simple weld-qualification tests, or even the use of simple air-pressure tests, or similar special tests, such as that of Fig. 17. This shows the checking of tractor fuel tank and frame structures being tested for airtightness.

Associated with this checking, there is the process of education of the individual welding operator as to the size of the deposited weld and the general qualities of appearance that lie within his control and that may be conveyed to him by the welding supervisor, the welding engineer, the welding instructors, or someone

from the inspection department. Whoever does the job, it is a phase of welding engineering.

Another type of inspection, which is usually very instructive and may be profitable, is that of examining structures that have failed in service. Such examinations usually yield certain types of information for a welding organization. If certain failures recur frequently, this may be the result of a weakness in the initial design of the structure or of improper welding technique.

Fig. 17.—The testing of the fuel tanks in this welded structure with air under pressure and soapy water represents one way of proving quality control for this special application. Inspection is a necessary phase of welding production and warrants study and careful engineering. (*Courtesy of R. G. LeTourneau, Inc.*)

Only by careful examination of the structures that fail can this be determined.

In connection with such examinations, it may also be to the interest of the company and the individual operators in the organization to have a system set up whereby the work of each man may be identified at any time after he has completed it, including after periods of field service. This is an organizational problem, but it is also one of welding control which may reasonably be considered to be a part of welding engineering.

Keeping Informed on Practice within the Industry.—One of the most important phases of engineering in a welding organization is that of keeping up to date with the developments and

new practices that enter the field. Research is constantly being done in establishments and by societies or groups of investigators who are qualified and equipped to do it. Such research is not necessarily a part of the welding engineering of many welding organizations, but it is distinctly to the interest of all companies to keep informed of the results.

There are several ways in which this can be accomplished. One of the very best is that of reading trade journals in the welding and metallurgical fields that present the technical as well as the practical shop practice aspects of current production. A thorough and regular examination of the leading literature of this type helps to keep an organization informed as to the development within the field.

Another very effective means is that of supporting the American Welding Society, whose journal and technical services give complete and detailed coverage of the results of research in the welding field.

The local section meetings of the society are also good sources of instruction, for they are primarily dedicated to the forwarding of the arts and science of welding and metallurgy and commonly attract specialists in the field to address the members of the local section.

Another very profitable phase of the local technical-society meetings is that they bring together members of local industries and result in an exchange of ideas.

Still another important means of keeping up to date is that of visiting plants in different parts of the country which are engaged in manufacturing similar products. Usually, such visits from one plant to another are of mutual value because of the exchange of ideas within the scope of the practice in the plants of both organizations.

Another important source of information is that of the engineering service that is given by vendors of equipment for arc welding. The manufacturers of equipment are busily engaged in research that will improve their product and therefore increase the effectiveness of their unit for manufacturing by the arc-welding method; and although usually the first interest of these engineers is that of promoting their own products, the information that they give is usually associated with fundamental welding problems.

Who Is a Welding Engineer?—The problem of describing just what the welding engineer should do has been more or less outlined by the description of the engineering problems encountered in welding. Obviously no one man can accomplish all the welding-engineering details or properly supervise all the various phases of the welding-engineering problems in a large plant. However, it may be said that any one who is actively and successfully engaged in the solution of the welding-engineering problem is doing welding-engineering work.

It is impossible to describe exactly what all the qualifications of a welding engineer should be, but three of the most important are as follows:

1. The welding engineer should have a shop, as opposed to white-collar, outlook. The organization of the procedures and control and the knowledge of the processes and operations in the plant must come from a firsthand shop knowledge, which cannot possibly be attained from "front-office" study, and the administrative problems that come with welding engineering can seldom be administered 100 per cent by swivel-chair office practice.

2. The welding engineer must know the physical layout of the shop in which the welding is being done, the names of the units produced and their parts, the names of the fixtures that produce them, the general language of the shop, and the procedures that are being carried out. He must be able to think clearly and objectively in order to organize the information and solve the problems arising in the welding of the plant's products.

Since the welding engineer's work is, in many respects, correlative and educational, the degree of success of the specifications and the procedures that must be set up to control the welding process depends on the cooperativeness of all the members of the organization involved. This makes it necessary for the welding engineer to know the members of the organization and to be known by them.

3. It is a very important phase of the welding engineer's successful functioning in an organization to be tactful, capable of getting along with people, of carrying responsibilities, and of promoting programs of organization and control within the company.

The educational background of a welding engineer does not necessarily mean a university degree in welding engineering.

That phase of the development of the welding art and industry and education has not been developed to the extent that full-fledged welding engineers may be produced by the universities or institutions of higher learning, although the technical information and training required to solve many of the more difficult problems that arise in a large or very specialized organization for the production of welded products do require information that is usually obtained in institutions of higher learning.

Whatever the educational background may be, men successfully involved in welding engineering always have had sufficient shop experience to be acquainted with the various factors and unsolved problems within their own organizations.

CHAPTER III

WHAT ARC-WELDING SPECIFICATIONS SHOULD SHOW

Specifications should give, as briefly and simply as possible, the answers to the reasonable questions that a workman might

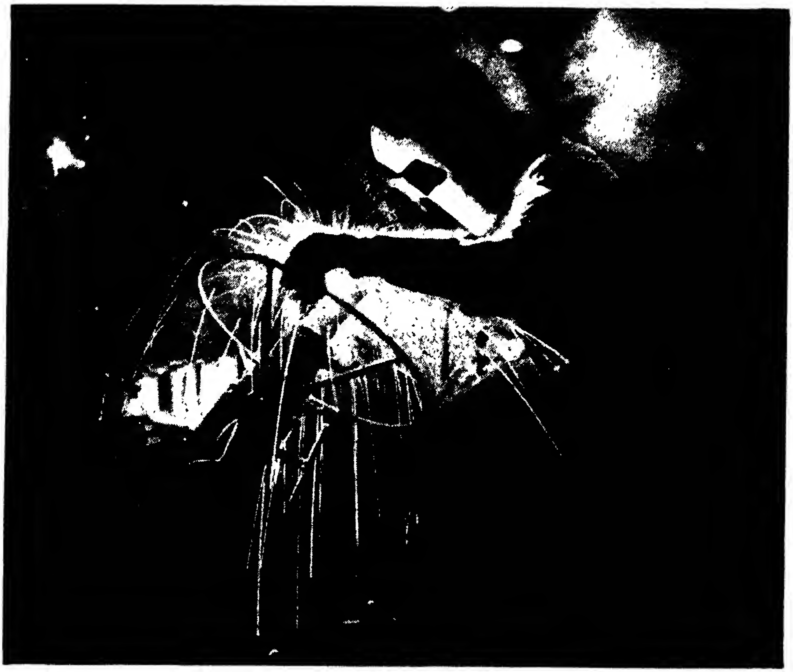


FIG. 18.—In the deposition of every weld, there are "manual" factors that constitute the welding operator's skill as well as "engineering" factors such as size, location, length, and other technical considerations. (*Courtesy of R. G. LeTourneau, Inc.*)

ask about the technical or engineering phases of a job to which he is assigned.

In any manual arc-welding operation, there is one group of factors, which may be termed the "manual factors," in the deposition of the weld that is entirely controlled by the arc-

welding operator's skill, such as the knowledge of how to operate the equipment; familiarity with the lead, holder, etc.; the ability to strike, hold, and manipulate an arc (see Fig. 18) and to direct it by various motions; and the manipulation necessary to control the weld metal and to place it where it is desired in a suitable quantity and of a suitable quality to produce a satisfactory weld (Fig. 19).

FIG. 19.—A considerable degree of craftsmanship and manual skill are required to produce the best weld possible even when all the factors such as size of weld, number of beads, type of electrode, and all other "engineering" information is given to the operator before he starts the weld. (*Courtesy of R. G. LeTourneau, Inc.*)

These factors lie within the control of the arc-welding operator himself and constitute his manual skill. It is with these factors alone that he should be preoccupied while he is depositing weld metal and, insofar as possible, all questions other than those pertaining to these factors should be answered for him before he starts.

The answers to the questions that do not pertain to the manual factors can be classified as the "engineering factors." These factors enter into the problems embodied in the following questions, which might logically be asked by every welding operator before he strikes an arc on a welded structure:

1. Where shall this structure be welded?

2. How much weld metal should be deposited? (or How large a weld should be made?)

3. What is the form of the finished weld? (In other words, What is a cross-sectional view of the finished weld?)

4. In what position should this be welded, and in how many passes?

5. What type of electrode should be used for this weld for each pass?

6. What size of electrode should be used for each pass?

7. What machine setting (what heat) should be reasonable for this particular weld to obtain the speed desired and the quality of weld required?

8. In what sequence should the welds on this structure be made?

The answers to the foregoing questions constitute the engineering factors concerned with the deposition of any weld.

Both the manual and the engineering factors in various classes of welding jobs differ considerably. The difference between welding very light gauge material and welding heavy structures presupposes a considerable difference in the specific requirements of manual skill on the part of the operator as well as considerable differences in the engineering factors involved.

There is, however, one difference between the manual factors and the engineering factors of making a weld, which is that the manual factors must be learned by a process of operator education on a specific type of job, whereas it is possible to present, with one set of generalized welding-symbol specifications, the answers to the engineering questions for a great variety of jobs.

There are certain classes of welding which require more rigid specifications, *i.e.*, for which the use of well-organized and standardized welding specifications is more important than for others. One classic example (the one in which probably the first and greatest progress was made in welding specifications) is that of pressure-vessel welding. Another large class, which is becoming more and more prominent in the welding industry today, concerns the use of arc welding to produce machinery or equipment on a mass-production basis. An example of this class is the "body-fabrication" department for the production of large modern earth-moving units of arc-welded construction (Fig. 20).

These earth-moving structures are produced in lots of 50 to 100 or more and a well-organized production line must be set up to manufacture the various substructures and structures in an orderly sequence. The individual arc-welding operator welds the same structures on each of the 100 units on the order.

This type of operation presupposes the standardization of the job, permits job analysis and education of the welding operator to each individual job, and presents the maximum opportunity for the use of a system of welding specifications to answer all

Fig. 20.—The department for fabrication of large earth-moving scraper bodies on a mass-production basis. The control and standardization of the "engineering" factors of welds on this large a scale becomes a matter of major economic importance. (*Courtesy of R. G. LeTourneau, Inc.*)

the engineering questions involved on all the structures and, therefore, put them completely under engineering control.

In an analysis of the factors involved in depositing a weld, there seems to be some difference of opinion as to what should be expected of an arc-welding operator. In order to clarify the statement made at the outset of this discussion, to the effect that the manual factors involved in a weld are all that the operator should be expected to be responsible for and that the engineering factors should be made available to him at the beginning of his job in complete and concise form, a brief discussion of the manual factors in terms of mass-production welding should be presented.

Manual Factors in the Deposition of a Weld.—The process of deposition of a weld by a welding operator is one that requires his undivided attention from the moment he strikes the arc until he breaks it and discontinues the welding. During this

process, many steps must be taken and many problems arise. The successful arc-welding operator has perfected the ability to meet the requirements of the job by a process of self-training and manual skill that alone will enable him to make a satisfactory weld.

It is the application of this accumulated skill that makes an arc-welding operator a specialized artisan whose services are purchased by a manufacturer of welded equipment, and it is to the interest of both the employer and the operator to have him exercise that skill as fully as possible on the job, without dividing his attention or ability in directions other than the deposition of weld metal.

The manual factors that continually preoccupy the arc-welding operator may be listed as follows.

1. *Familiarity with Welding Equipment.*—Early in the process of educating an arc-welding operator, he is trained in the manual details of the use of an arc-welding lead, the holder, the electrodes, in the names of the tools that he uses, and in the correct method of their application to his particular job.

He also is schooled in the habit of safe operation of this equipment and must always be mindful of the details that ensure his safety and the most efficient use of his tools.

2. *Knowledge of How to Adjust the Welding Machine.*—There are certain adjustments on welding machines in general that every operator must know how to accomplish, and the specific details of the particular machine that he is using must be familiar to him before he can use it satisfactorily. These are matters of experimentation and of skill in observation on the part of the welding operator. During the welding process he must continually be on the alert for slight variations in current or for indications that his machine is improperly adjusted.

3. *Ability to Strike, Hold, and Manipulate an Arc.*—A fundamental part of the skill of an arc-welding operator is the ability to begin a weld properly, to strike an arc, to hold it by manual dexterity and coordination of eyes and hands, and to direct it as a tool in the place where it must be held to progressively deposit a weld. The skill required to strike and hold an arc, to break it properly at the end of a weld, and to recommence with a new electrode is a vital part of the training of a welding operator and an item of which he must continually be mindful during his

work. The detail of cleaning the crater at the end of a weld, prior to the striking of the arc in the same place with a new electrode, is one that requires attention and knowledge, and the variation of these operations from one job to another using different types of electrodes further complicates the operator's problem.

4. *Ability to Direct an Arc to Control Weld-metal Deposition.*—During the deposition of a weld, the welding operator must be continually on the alert, moving his hand and his electrode and studying the progress of the crater with reference to the members of the joint in order to produce a sound and satisfactory weld.

This process is one that requires attention and alertness every fraction of a second that the operator is depositing the metal. A very slight variation in his weaving motion may cause undercuts, or a slight difference in length of arc may cause lack of penetration, overlap, slag inclusion, or any one of the various flaws that may occur in welding. Without constant attention, welds such as those shown in Fig. 21 could not be made.

Variations in fit-ups and in cleanliness of the plates are variables that enter into this phase of the welding operator's work and require constant vigilance on his part.

A slight variation in the analysis of the plates from inch to inch of the weld may make a considerable difference in the way in which the weld metal flows and is, therefore, still another of the variables that require the welding operator's full attention during the laying of a weld.

The difference in the steps required in the manipulation of the arc for the deposition of welds in different positions, *e.g.*, a strictly down-hand flat weld and a vertical weld, are considerable. The skill of a welding operator and his classification may be based to a great degree upon his ability to manipulate an arc and deposit weld metal with the joints in different positions.

5. *Ability to Control Size of Weld and Form of Weld during Deposition.*—A welding operator should not be expected to know how large a weld should be made to weld a joint of a given type and size with a given material. That is an engineering problem, which should be decided during the design of the unit.

The size of the weld, however, should be conveyed to the operator before he starts to weld, as well as the number of passes that he should use to make that weld (assuming a normal fit-up),

since the control of the size of a weld by a welding operator is a matter of skill that requires his attention during the deposition of the weld.

In order to produce a pass or a complete weld of a given size, the welding operator must hold his electrode at a given angle, must oscillate it properly, and must be mindful of his arc length and of his speed of travel.

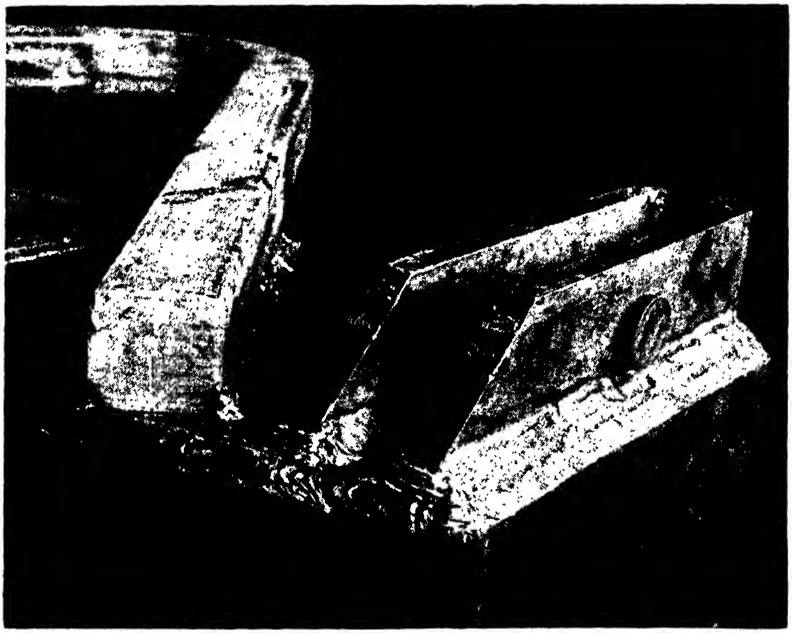


FIG. 21.—The ability to control the contour and deposition of welds on a structure such as this requires a fundamental period of training on the part of the welding operator. Note the size, the careful tie-ins, and the multipass construction of these welds. (*Courtesy of R. G. LeTourneau, Inc.*)

Each of these items varies with the position of the work, and in order to get as high-quality a weld as it is possible to produce, each item must be accounted for in advance, thought about when the welding operator begins to deposit the weld, and carefully considered during the welding process.

If a welding operator can perform correctly all the steps described above as manual factors in the deposition of a weld, he is doing as much as should be expected of him as a skilled craftsman. Consideration of the engineering factors of where

to weld, how large a weld to make, what type and size of welding electrode to use, what form of joint to make, and what sequence of welding to follow will only divide his attention and detract from his best efforts. These are engineering problems that should be decided before he starts to work and that require technical knowledge beyond what he should be required to have to perform the manual factors in welding.

Welding specifications of an engineering nature should therefore be provided to cover each of the factors not covered by the manual factors just described. A discussion of these factors, their relative importance, and how they may be specified simply and in good engineering form will follow.

Engineering Factors in Arc Welding That Should Be Covered by Specifications.

1. *Location of Weld.*—This is a matter of considerable importance from the standpoint of control, since at times welds may be made intermittently, rather than by completely welding every joint throughout.

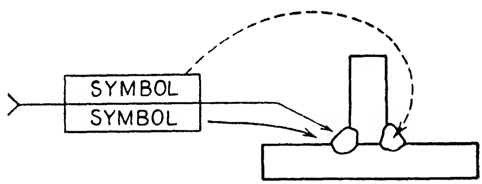


FIG. 22.—The base line from which the American Welding Society's welding symbols start is an arrow that shows the location of the weld; the position (above or below the line) of the data referring to welds on either side of a joint is as shown.

The establishment of a means of identifying each weld and its location is the first step in setting up a welding procedure and lends itself readily to the symbolizing method established by the American Welding Society.

The use of an arrow, the head of which points toward a joint, indicates the location of the weld, and the additional information placed below or above the shaft of the arrow refers to the weld on the near side of the joint and that on the far side of the joint, respectively (see Fig. 22).

The use of a symbol of this kind on the blueprint will immediately answer the question, "Where shall this be welded?"

2. *Size of Weld.*—This is one of the most important factors in the manufacturing of welded equipment because it is one of the

instances where the exercise of proper control is of great economic importance.

For any given joint (granted a normal fit-up) involving any special type and thickness of material, there is a correct size of weld (assuming sound weld metal, which should be expected of an average operator) that will satisfactorily fuse the plates and make the weld correct. This size should not be reduced for fear of failure, nor should it be increased, for very important economic reasons.

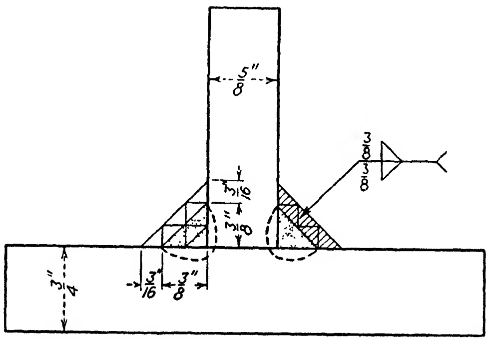


FIG. 23.—Control of weld size is important. To underweld results in failure, but to overweld is expensive. Here the weld is made only half again as large as specified according to dimensions, but it contains over twice the amount of weld metal specified.

Overwelding should be condemned by inspectors just as severely as underwelding. To overweld greatly increases the cost of the welding process, as may be demonstrated by Fig. 23, which shows that if a weld is made only half again as large as the specifications call for it takes over twice the weld metal and twice the time to deposit.

If the size of a weld is properly specified to the arc-welding operator, he then may be expected to maintain that size and should consider it a part of his job as a skilled artisan to do so. If it is not specified, however, the average welding operator will overweld, so that there may be no likelihood of the weld failing and of his work being criticized.

Overwelding not only costs more from the standpoint of labor and materials, but also adds increased stresses and heat with the resultant detrimental distortion and grain growth in the welded joint. Figure 24 indicates the method by which the size of a

weld may be shown on the welding-symbol shaft, originally shown in Fig. 22, so that the welding operator may know what is expected of him with regard to weld size.

3. *Form or Cross-sectional View of Weld.*—The form of the completed weld on many structures is obvious when the joint is examined; yet, often, where there is a special joint preparation, including a J type joint groove or V type joint groove, there may

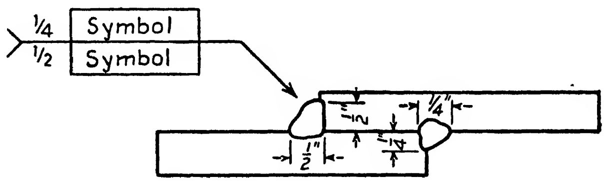


FIG. 24.—The size of the weld is then shown by dimensions in the proper relation to the base line. (Dimensions on welds as given on this structure are only to show what the symbol indicates and would not otherwise be used.)

be specialized views of the weld as it is completed that are not so obvious upon immediate examination of the joint to be welded.

Figure 25 shows how the cross-sectional view of a welded joint may be shown by a symbol on the blueprint in such a way as to indicate a completely flush weld, a slightly crowned weld, an ordinary fillet type weld, a weld with unequal length legs, or other specialized welds.

4. *Position of Joint for Weld Deposition.*—With special reference to repetitive mass-production welding jobs which are

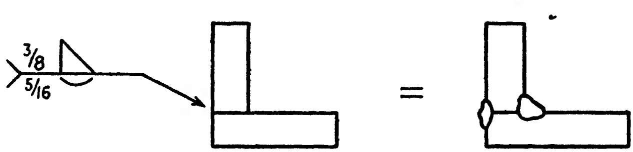


FIG. 25.—This diagram shows how the form of the weld (its cross-sectional view) may be shown on the blueprint to help the operator visualize the weld.

standardized, the matter of position of joint is a very important one.

In the first place, it is well recognized that a weld that can be deposited in the down-hand position (completely flat) can be made more quickly, with greater assurance of soundness and good appearance, and by a less experienced operator than a weld in any other position.

On a repetitive job, fixtures may be supplied whereby a unit may be welded with each weld on the structure consistently deposited in a certain position from one structure to the next. It, therefore, becomes reasonable and profitable to specify in the welding-symbol system the position in which each weld shall be deposited. It presents the welding operator with a written order to deposit the weld in the most desirable position from the standpoint of economy of procedure and sequence on that particular structure.

Without such specifications, it is not unusual for welds that could be made in the completely down-hand position to be deposited in the horizontal-fillet position or sometimes even the

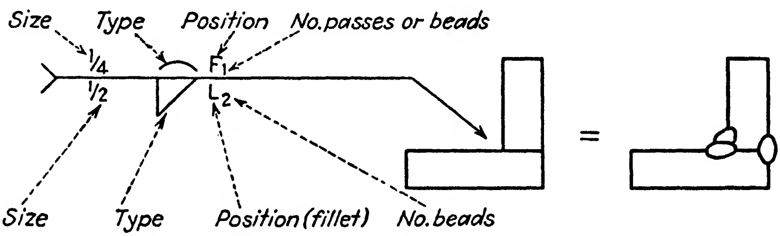


FIG. 26.—For showing the position in which a joint is to be welded and the number of beads (or passes) to be used, the letter indicating position and the number indicating number of passes are satisfactory.

vertical position simply because the welding operator feels that the additional handling to position the weld is more difficult than it is worth.

If the welding engineer is expected to put down the specifications for the position in which the weld shall be deposited, due thought should be given as to how it can be done economically in the jig-and-fixture design.

Figure 26 shows one method of prescribing the position in which a weld shall be deposited, along with the regular symbol which shows the size of the weld, location of the weld, etc. The letters V for vertical, O for overhead, H for horizontal, L for horizontal fillet, and F for flat serve the purpose satisfactorily.

5. *Number of Beads of Weld Metal in Joint.*—The number of passes required on a normal joint of a certain size on a given structure is an engineering detail that should not be underestimated in importance, nor should it be left to the welding operator to decide.

It is not inconceivable that a half-inch fillet weld, deposited in the down-hand position, might be made in one pass on certain joints and yet might not be made satisfactorily in two passes on other joints. The best assurance of a good weld on certain structures requires that a given number of passes be made on a particular joint (granting a normal fit-up). It may be that the preheating effect of a small pass put in prior to the deposition of the large volume of weld metal in the joint is required to get proper fusion. This phase of the procedure may be specified on a print as shown in Fig. 26. After the letter indicating the position in which the weld will be made, a figure appears which indicates the number of passes to be made in the joint.

There is a reasonable limit to the size of the weld that can properly be deposited in one pass. If that limit is exceeded, either penetration will not be achieved or it may be that a grain growth will occur in the unduly large weld which will substantially weaken the structure of the weld metal itself.

6. *Type of Electrode.*—In almost any welding shop, there is more than one type of welding electrode available. Usually there is the AWS E 6010 type of welding rod for all-purpose welding and all-positioned welding. There also is likely to be the AWS E 6012 type weld for all-positioned welding where the fit-up is not consistently good; in such cases, this type of electrode is commonly used. A third type of electrode, for almost any shop which has studied its welding procedures and has taken advantage of the greater speed and efficiency of positioned welding, will be available in the AWS E 6020 type of electrode, which is specialized for down-hand positioned welding.

With this variety of electrodes available in a welding shop, full advantage should be taken of the specific application of each type of welding rod to each point on a structure; furthermore, full directions should be given to the welding operator as to which electrode should be used on a particular joint, so that he may know what is expected of him on that part of the welding job.

The earth-moving unit (an "angledozer" bowl) shown in Fig. 27 is an example of a unit where it is economical to specify the E 6020 type welding electrode for long welds and the E 6012 for others on the unit.

There may be times when it is essential that a certain type of welding electrode be used in a certain joint in order to give

strength, appearance, or other qualities to that weld which cannot be obtained by the use of any other electrode. If the choice

Fig. 27.—Often it is not economically practical to position structures for 100 per cent down-hand welding. Such is the case on this earth-moving unit. To specify fast-flowing down-hand electrodes for long welds and an all-position electrode for other welds is profitable. (*Courtesy of R. G. LeTourneau, Inc.*)

of electrode is left to the welding operator, he naturally will choose the electrode that he thinks will be the easiest to use or that may be most handy, which may not be the type of electrode that the engineering department would desire on that particular joint.

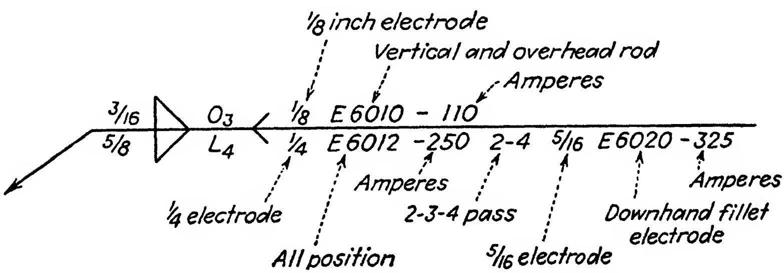


Fig. 28.—Type of electrode, size of electrode, and machine setting for each pass are "engineering" factors, each of which represents an important effect upon the cost or quality of welds. They may be designated on the print as here shown.

Figure 28 shows the method by which the type of electrode to be used may be represented on the welding-symbol setup.

7. *Size of Electrode.*—Side by side with the type of electrode to be used for each welding joint, the information as to the size of the electrode for each pass should be shown.

It is often essential that a first pass be made with a small electrode and that the second pass be made with a larger electrode to give the maximum speed of deposition and proper penetration for a weld of a certain size. Without being specifically told the size of electrode desired, the operator may make all the passes with the large electrode and not get proper fusion or penetration.

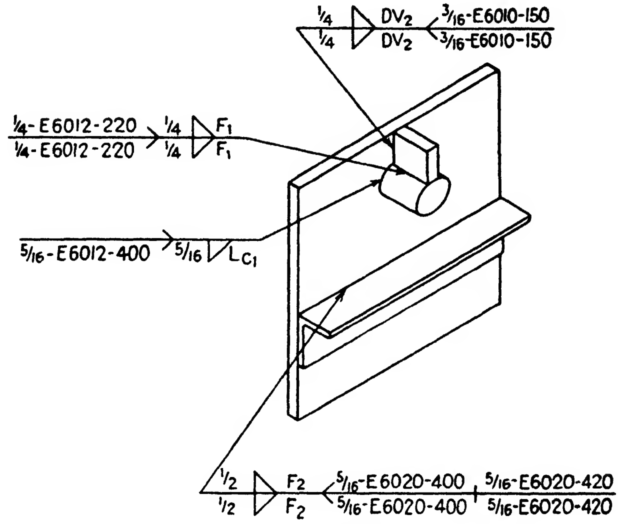
Figure 28 shows how the size of electrode may be represented as a fraction preceding the type of the electrode shown in the symbol.

8. *Machine Setting for Weld.*—Within certain limits, any skilled welding operator would use a certain heat for a certain size and type of welding electrode. Sometimes, however, if he is not given a specific limit which will allow him to deposit weld metal at the maximum safe speed and heat by a reasonable machine setting, he may not use the maximum heat allowable and so increase the length of time required to deposit certain welds. On the other hand, he may use more heat than he should, and so jeopardize the quality of the weld. As shown in Fig. 28 (or Fig. 29), the method of showing the machine setting as a number of amperes or by dropping the last zero on the ampere number (20 for 200, 40 for 400, 45 for 450) gives the complete story as to the machine setting that should be expected on a certain job. This should be carefully studied and prescribed by the welding engineer, with the understanding that the specification is for a normal job with a normal fit-up. It should be also checked occasionally with an amperemeter when the operator is actually welding, so that his welding heat may be indicated to him accurately. This is not always the case when he sets his machine by the indicator on it.

Figure 29 shows a blueprint of a structure (without setting up dimensions) with complete welding symbols as it would be used in the shop.

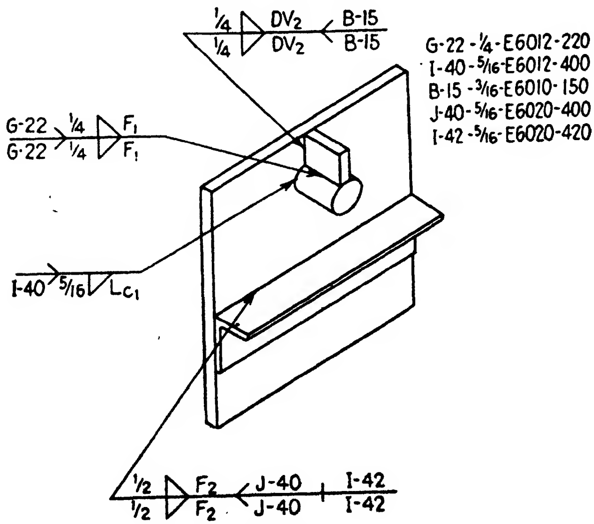
According to standard practice on all production items in one large manufacturing organization, the information shown in Fig. 29 is further symbolized and boiled down as shown in Fig. 30.

9. *Welding Sequence for Structure.*—In a manufacturing organization where the welding operations are standardized and



PRINT A

Fig. 29.—Example of the complete symbol control of engineering factors on a blueprint of a structure. Such a print would also show fit-up dimensions and separate part identifications. (See Fig. 30 for more symbolized but simpler means of showing the same welding information.)



PRINT B

Fig. 30.—The symbolized information in Fig. 29 is simplified and grouped as shown above on all production items in the shops of one of the major producers of modern arc-welded equipment on a mass-production basis.

where separate fixtures are made for substructures and structures, the sequence of welding can be organized around the process of putting parts into the fixture and welding the parts, step by step, in an orderly sequence.

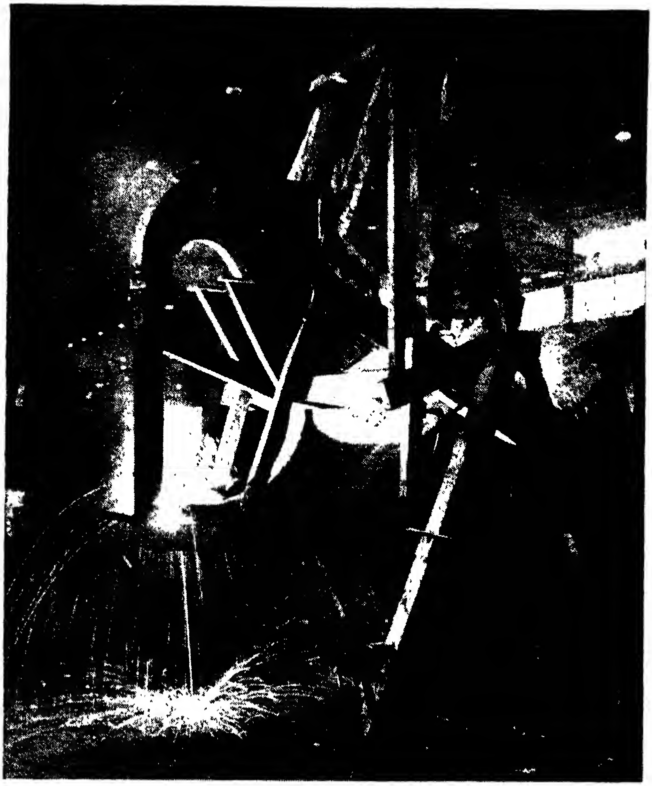


FIG. 31.—In order to standardize the sequence of welding on such structures as this, an operation sequence sheet is a practical device (see Fig. 32). (*Courtesy of R. G. LeTourneau, Inc.*)

The sequence for a simple structure usually resolves itself into starting with a particular weld and continuing as the part is turned in the fixture until the last weld has been made.

For complicated structures such as the one shown in Fig. 31, or for structures where the sequence of welding should be made in an irregular fashion (different from the way they present themselves in the normal turning of the fixture), it is very effective to build up a simple check sheet for the sequence of welding.

Operation: Setup and Weld					
Cl. Tournapull Deck-plate Structure		R1964			
Elements		Occurrence			
1st operation					
1	Pos. & clamp ball base & main plate in jig............				
2	Pos. & tack side plates & hitch ball base to plts.......				
3	Weld side plt. to hitch ball base 1st pass.............				
4	Turn and weld side plts. to main plate, outs & ins . ..				
5	Turn, weld side plt. to ball base 2d pass........... ..				
6	Turn, pos. & tack top plt. to side plts................				
7	Turn, weld top plt. to hitch ball base.......				
8	Turn, weld side plt. to main plt. (top)...............				
9	Turn, weld side plts. to top plate....................				
10	Turn, weld side plts. to ball base (ins)...............				
11	Turn, pos. and tack gussets..................				
12	Turn, weld top gussets to top plt....................				
13	Turn, weld side gussets to side plts. & top gussets ..				
14	Turn, weld side gussets to main plt..........				
15	Turn, weld gussets & top plate to main plt (end)......				
16	Turn, pos. tack & weld cover plt rings.....				
17	Turn, remove box beam (jig)............				
18	Pos. tack & weld rounds to main plt.................				
19	Remove str. from jig and stamp symbol.............				
20	Straighten deck plate.................				
2d operation					
1	Load str. on jig..................................				
2	Pos. & tack kennels and pipes to str................				
3	Weld pipes to str..................................				
4	Weld kennels to str.................				
5	Unload from jig..................................				

Name____________________

Badge Number________________

Shift_____________________

Date_____________________

Fig. 32.—This check sheet gives the operational sequence for both the setup and the welding of a complex welded structure. The operator soon learns the sequence and follows it because it is the way in which he first learned to do the job. (*Courtesy of R. G. LeTourneau, Inc.*)

This check sheet may be presented with the blueprint to the operator and shows him the order in which the welds on the structure are to be made.

Such an instruction sheet is shown in Fig. 32. It may be incorporated into the blueprint on the tracing, if it is short enough so that this can be done without crowding the information on the print, thereby simplifying the instructions by having them all in one piece. The operator soon learns the sequence and follows it without need for reference to the sheet after the first few units are built. The sheet shown in Fig. 32 is also used as a daily production record of the operator who builds the structure.

With the foregoing facts in mind, the welding operator can proceed to start his arc after he has positioned the weld, prepared the correct welding rod, and set his machine properly. He can deposit the weld in accordance with the desires of the welding engineer or the engineering department as indicated by their written specifications on the blueprint, giving his full attention to the problem of meeting those specifications.

Wherever this degree of control is established and followed, the expenses of overwelding and of time lost by the operator in trying to figure out what he should do and how he should do it will be eliminated for all practical purposes. A considerable increase in the degree of economic advantage will be realized by the establishment of such a control for any mass-production welding operation, because it standardizes the operation and therefore standardizes the product, and because it carries a properly engineered series of operations to an effective conclusion without dividing the attention of the skilled operator from a perfect job of manually depositing weld metal.

CHAPTER IV

PREREQUISITES OF, AND ECONOMIC BENEFITS FROM, ENGINEERING CONTROL

When the management of a welding organization commits itself to the policy of detailed and complete control of the engineering factors in arc welding, it not only undertakes a program that will be very profitable if carried to a practical and reasonable conclusion, but also obligates itself to certain provisions and undertakings.

Probably the most important prerequisite to the phase of engineering control which specifies the position in which welds shall be deposited is that of furnishing jigs and fixtures that make possible easy, rapid, and accurate setting up and that of positioning the welds of a structure for the most economical welding.

Jigs and Fixtures.—While jigs and fixtures are usually considered in the light of the control of the positioning of structures, they also control a very important phase of the welding manufacturer's processing, that of setting up the structures for welding.

This setting-up process should be carefully controlled because it, in turn, affects two important and economically significant factors in the manufacture of welded equipment, (1) the labor involved in positioning the parts and tack welding them together for welding and (2) the positioning of the parts positively in the proper relationship so as to prevent gaps and poor fit-ups. Both are extremely important in welding economics and will be discussed in a later paragraph.

Arc-welding jigs and fixtures may be generally classified as setup fixtures, welding fixtures, or combinations of the two.

An example of a fixture that is used for setting up parts in their proper relationship and tacking them together, without providing for positioning the part for welding, is shown in Fig. 33. Such a fixture is made primarily for the positive, accurate placing of parts in their proper relationship with the least motion

necessary and, if possible, without any measuring by the man who sets up the parts as he places them in the fixture. After they are located in the fixture, they are clamped in the simplest and most positive fashion possible and tack-welded together.

Such a fixture should be simple in design; should have positive stops against which certain surfaces of the component parts of a structure come to rest, and which automatically locate them in the proper relationship to the other parts; should have simple clamping devices that do not obstruct the putting of the parts into the fixture's frame; and should be made so that it is possible

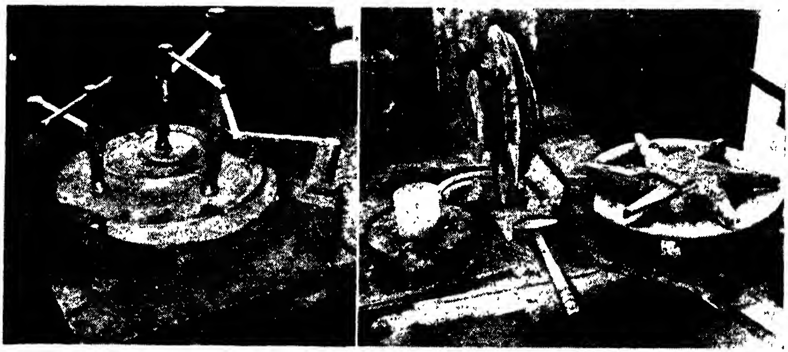


FIG. 33.—These set-up fixtures to remove the hand-measuring and laborious positioning of parts for this arc-welded structure and its two substructures result in real economy of human effort, standardized structures, and simplified operations. (*Courtesy of R. G. LeTourneau, Inc.*)

to tack-weld the separate parts of the structure together at each critical point, so that only the necessary places will be tacked.

Some welding is done in such setup jigs, especially when box sections or box structures are built in which inside gussets are placed that must be welded prior to putting on the top plate enclosing the inside gussets within the box section.

Studies of the amount of welding and the length of time it takes to deposit welds in different positions (*e.g.*, the horizontal fillet or vertical position compared with the down-hand position) indicate whether it is more economical, in a given case, to make such a setup jig or to make a combination setup jig and positioning fixture.

Another important aspect of the setting-up process is that it requires a certain amount of handling of parts and a certain amount of time which, if cut to a minimum, can more efficiently

be done by the arc-welding operator who is going to weld the structure than by a separate workman who does the setup and then turns the parts over to an operator for arc welding. It is often a considerable advantage, from the standpoint of most effectively keeping a crew of men working, if the arc-welding operator can set up his own structures.

Under this arrangement, the welding machine that the operator uses may not be in operation quite as much of the time as if a separate setup man did the job, but a setup man requires a welding machine in order to tack-weld the parts together. If the setup fixture is properly made so that no tedious measuring is required, it takes the arc-welding operator no longer to put the parts together and to tack them than it would for someone else to do it, and there is no waiting while the setup is being completed.

Still another item of some importance is that the setup operation will often be more carefully done if it is done by the man who is going to weld the structure. A slight variation in the way in which parts are tacked together, especially if there is any deviation from the normal in the cutting or forming of some of the parts, makes it possible for the setup man to control whether a structure will have proper fit-up or whether the parts will leave gaps that will be expensive to fill. If the welding operator does his own setup work, he probably will be more mindful of the importance of making a good fit-up than would a man making setups for someone else to weld.

Figure 34 shows a welding-structure positioner designed to rotate so that almost all the welds in the structure may be welded in the down-hand position. This is a simple positioner for the structure shown in Fig. 33.

Such a fixture justifies its existence on parts that have enough welds running in any one plane to make handling in the positioning fixture less expensive than the time required to make the welds in the position in which they would be without the benefit of a mechanical positioner.

The advantage of positioning a weld can best be determined by actually welding in different positions and using a stop watch to make time studies, but ordinarily it can be considered that if the welds in a structure can be positioned 20 to 50 per cent of the welding time may be saved.

It is not always economical to position every weld in a structure. Often it is very satisfactory to do the setting up of such structures or parts into a completed structure in the same fixture in which it is welded.

Figure 35 shows a fixture in which the parts are positioned, tacked together, and welded in the same fixture. This fixture rotates in one plane. In the design of the fixture, the parts are

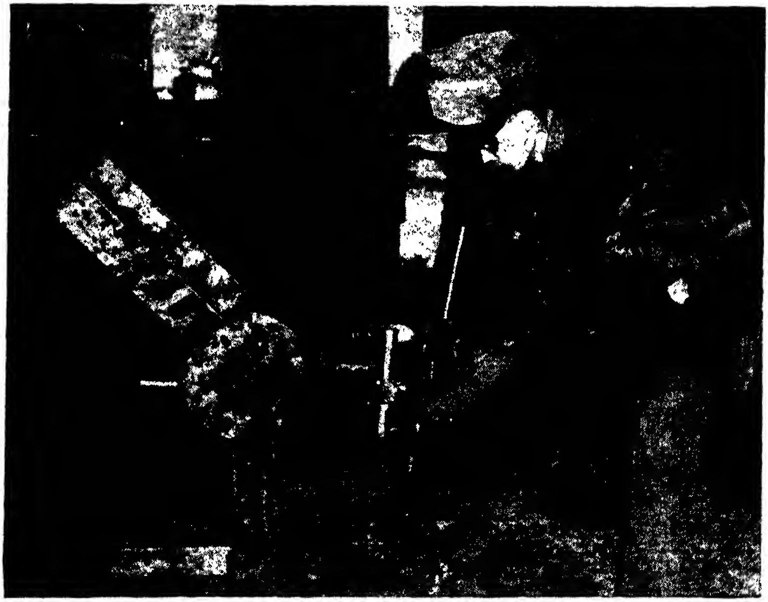


FIG. 34.—This simple positioning fixture allows the welds on this structure (setup in Fig. 33) to be welded in the down-hand position. Specifications may now call for down-hand welding because the means of positioning can be provided. (*Courtesy of R. G. LeTourneau, Inc.*)

set up into it in such a way as to make the longest weld or the greatest total amount of welding parallel to the plane of rotation, so that those welds may be deposited in the down-hand position.

In such a fixture, the objectives of control of setup and control of welding position may be achieved, and the time required for removing the structure from a setup jig into a positioning fixture is saved.

With a fixture that is properly designed and that can be turned to the same position every time with the same structure in it, the position in which the weld shall be deposited may be

brought definitely under control. Without such a fixture, it is difficult to establish a control of the position in which welds will be deposited, especially on complex structures.

Control of Fit-up of Parts.—Another factor in manufacturing arc-welded equipment, and one that has a tremendous effect upon the degree of completeness and success of a method of control, is that of fit-up.

Before the size of electrode, type of electrode, machine setting for each pass, and the number of passes required for a weld may

FIG. 35.—Both the setup and weld-positioning functions are served by this fixture for the standardized and controlled production of these heavy earth-moving unit parts on a mass-production basis. (*Courtesy of R. G. LeTourneau, Inc.*)

be specified to fill the requirements of any given job, the degree of fit-up must be controlled.

It would be ridiculous to specify that the welds shown in Fig. 36, for example, should be made in one pass using a fluid, down-hand type of electrode (*e.g.*, an American Welding Society designation E 6020 type of electrode) of a relatively large size with a high heat in the down-hand position if the parts did not fit together properly as shown, because obviously such a procedure would be impossible with any large gaps in these joints.

Granting that the fixtures used for setting up structures are designed to use normally correct fitting parts and that the setup

operation is properly done, the problem of fit-up resolves itself into either templates used in the manufacture of the parts themselves or poor workmanship.

Speaking in terms of welding on a mass-production basis (where the frequency of parts of the same kind is great enough so that templates may be studied and workmanship perfected), a very careful study of the cutting fixtures, templates, and

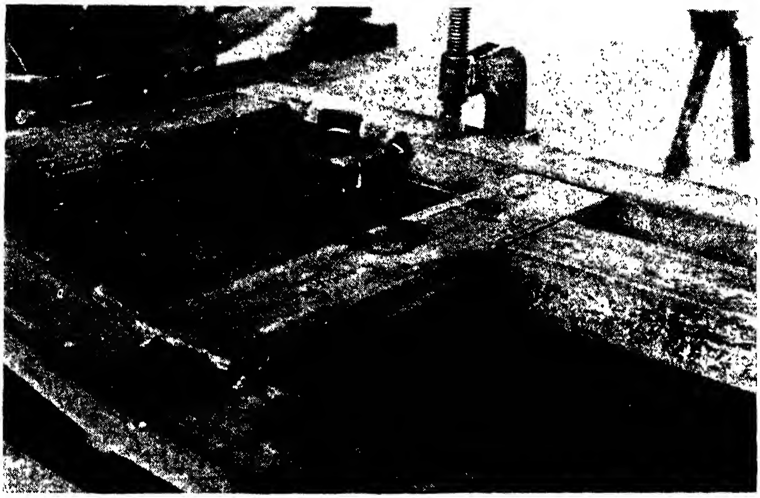


FIG. 36.—A consistently good fit-up of parts on structures such as this part of an earth-moving unit's side sheet must be achieved if size and type of electrode and setting of the machine are to be specified. Good fit-up is half the battle for both the control and economy of welded construction. (*Courtesy of R. G. LeTourneau, Inc.*)

procedures is probably the greatest requisite for properly fitting parts.

In the original design of a unit before it is in the production stage, templates drawn up by the engineering department are made for the parts, which are then cut from them. The templates should be carefully kept and compared with the parts as they are used in the structure at the time it is built. Almost always there are corrections to be made in the parts, and those corrections should be made in the templates also.

After the experimental unit has been made, tried, and found to be satisfactory, then a "pilot order" of two to five structures may be made, at which time jigs and fixtures are made for the structures and substructures involved in the unit.

At the time that these fixtures are made, it is often found advisable to make slight changes in the form of certain parts, and again careful checking to correct the templates for those parts ensures proper fit-ups on the subsequent orders.

Cutting templates should again be very carefully examined during the process of building the structures for the pilot order of units, since small variations in fit-ups can be ironed out and the total quality of the fit-up of the units much improved.

After the jigs and fixtures have been made for the structure and the templates corrected to the parts as used in the pilot order, the templates should be dependable, and it should be possible to place a production order with the full expectation that the parts will fit.

On the first of such production orders, a careful check up should again be made of the degree of fit-up on all parts and correction of templates be made in case there are irregularities of fit-ups in the unit.

It should be borne in mind during this last check up that if all the parts of an order are found to fit poorly in the same way, then there is probably a mistake in a template or an error in the basic procedure of cutting the part. If, however, part of the order fits properly and part of it does not, then the problem is an educational one in perfecting the workmanship of the operator who cut the parts or in the manipulation of the template during the cutting process.

Maintenance of Equipment and Education of Workmen.—Granted that the proper jigs and fixtures are available to workmen who will be operating under a strict control of welding from the engineering standpoint, and that the templates and equipment of the workman who makes the parts are in good condition, it is absolutely essential that some method of correct maintenance of these parts and equipment should be provided.

If the jig-and-fixture department takes care of the maintenance of the fixtures, it falls to the foreman of the welding department to call for service on any fixture that gets out of adjustment in order to protect the interests of his workmen and also to maintain production schedules for an effective control.

The arc-welding operators themselves should be taught the elementary phases of their operations as affected by the welding-symbol control on the prints in order that they may know what

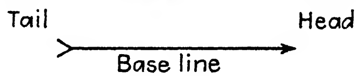
the symbols mean and follow them. Such an educational course is made most effective by being taught by supervisors of welding (the welding engineer or some well-informed welding instructor or welding foreman) to apply specifically to the particular system of symbol control that is used in that plant, and should be given

ARC WELDING AND WELDING SYMBOLS COURSE

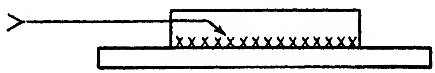
Lesson 34

ARC WELDING SYMBOLS

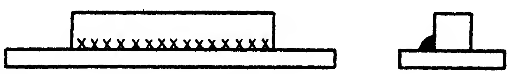
Simplicity is the advantage of arc welding symbols. A symbol fundamentally begins with a simple arrow, consisting of a head, base line and tail.



To show the location of a weld an arrow is drawn with the head pointing to the joint where the weld is to be placed.



Now to show whether the weld is on the near side of the joint facing the observer



or on the far side—

The symbol specifying the type of weld is placed under the arrow in the first case

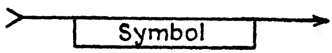


Fig. 37.—A step-by-step description and diagraming of the symbol system in a series of lesson and quiz sheets is an effective means of teaching the symbol system of control to the welding operators in an organization. This sheet is the first in the first lesson of the welding-symbols course. (*Courtesy of R. G. LeTourneau, Inc.*)

to operators about the time they end their manual arc-welding training and start their production-welding work.

A series of lesson sheets, such as the one shown in Fig. 37, can be built up rather simply and can give the welding-symbol lessons one step at a time in such a way as to make them clear and not too concentrated for the student welding operator.

These may also be used to teach welding inspectors, time-study men, beginning draftsmen, and others who should be able to read and interpret the welding-symbolized engineering-control information.

Improvements in Products Due to Complete Control.—One of the greatest benefits of a complete engineering control of the welding process is that it results in standardizing of parts, structures, and units and in the interchangeability of parts which is essential to all mass-production work.

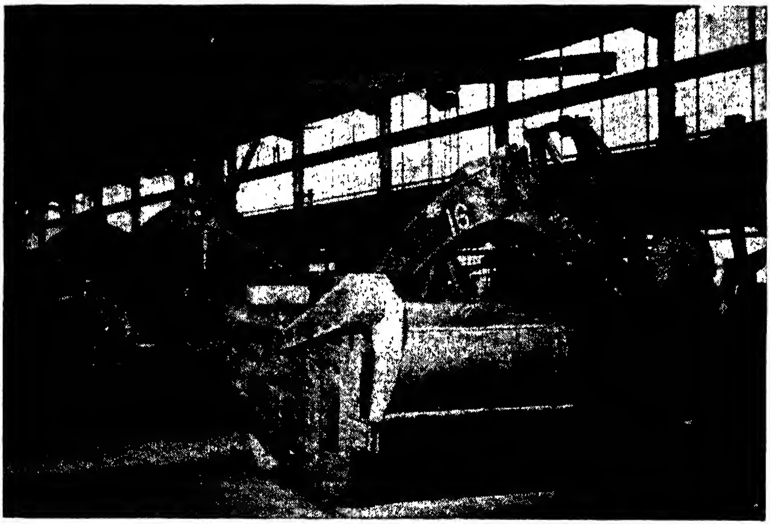


Fig. 38.—The structures that make up these large earth-moving unit bodies were built on the same fixtures by the same workmen and according to the same procedures. They are therefore uniform in appearance, interchangeable in assembly, and good examples of controlled mass-production welding. (*Courtesy of R. G. LeTourneau, Inc.*)

The large welded machines shown in Fig. 38 being progressively assembled on a production and assembly-line plan would be very much more expensive and less effective in operation if they had to be "hand-tailored" part by part and structure by structure.

The fact that every substructure and structure that goes to make up these units is made in a fixture by a skilled and trained workman who follows a very rigid control of welding, including all the engineering factors of control, makes the parts interchangeable with one another on any machine of that type and requires a minimum of special attention during the assembly work.

This allows parts to be exchanged from one machine to the other, makes possible repairs in the field by sending a new structure to take the place of an old one, and makes possible the standardization of all the operations required to manufacture and assemble this unit.

The quality of the workmanship done on any welded structure on a mass-production basis is of necessity better when the operation has been standardized and placed under strict engineering control.

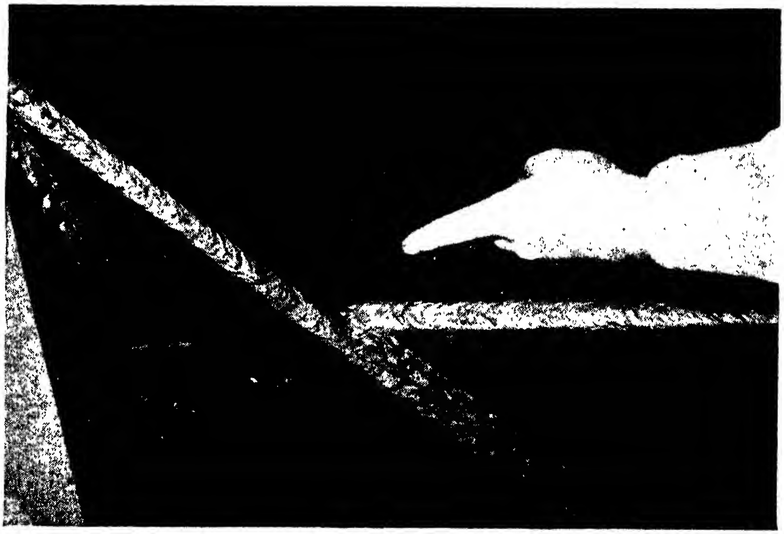


FIG. 39.—The multipass horizontal-fillet welds shown here required more time for deposition, more manual skill, and more cleaning time than the better looking, neater contoured, and completely positioned weld (being pointed at and bordering the hand). (*Courtesy of R. G. LeTourneau, Inc.*)

This is especially true of the quality of welds, because if a given weld is deposited on a structure with the same number of passes on a standardized fit-up in the same position, using the same type of electrode, the same machine setting, and the same size of electrode by the same operator time after time in the same way, the welding operator becomes much more skilled in his operations. He can then produce a consistently better weld than if he were putting it in with different types of electrodes, in different positions, and with a varying procedure from one unit to the next.

Figure 39 shows the difference in the appearance (which is usually a good indication of the position in which welds are deposited) of welds deposited in different positions. The multipass horizontal-fillet welds took more time, more skill, and more cleaning time but made no better welds than those deposited in the down-hand position.

Aside from the fact that joints usually cost less to weld in the down-hand position, the improved appearance of the positioned weld over the multipass horizontal-fillet or horizontal weld is a factor in favor of the positioned weld.

Although many of the welds made today do not require dressing down, nor is the appearance of the finished weld so far as one or many beads is concerned considered especially important, still it is true that a weld deposited in the down-hand position can ordinarily be made to look better than a multipass weld, especially in the hands of a relatively new operator.

Fundamental Economy Made Possible by Control.—By far the greatest achievement and most important accomplishment made possible by the complete engineering control of arc welding is the reduction of cost due to the elimination of wasted labor and material in the welding process. Chief among these sources of waste are the loss of weld metal and labor due to overwelding and to welding up gaps where a poor fit-up has occurred.

Additional weld metal deposited, beyond the reasonable assurance of a sufficiently large amount to fuse the members of a joint together, is a costly waste of time and material.

Without the benefit of specific control of weld sizes, overwelding is a very common source of waste. This is brought about by the natural human desire to do the job on the safe side so that the weld will not fail, and therefore leads to the deposition of larger welds than is required for that particular joint. This is not entirely confined to the workmen; for it is often observed that inspectors will inspect very rigidly for underwelding but will never even comment on overwelding.

A weld that is made one-half larger than it should be requires over twice the amount of welding metal and therefore over double the time. Also, the additional amount of heat and weld metal concentrated in that one place may make an inferior joint because of the concentration of additional stresses and the greater amount of grain growth at the weld. This control of

weld sizes, maintaining them up to the required size but down to the properly engineered amount of weld metal, is one of the most significant sources of economy in the manufacture of welded equipment.

The importance of bringing about a control that directly or indirectly decreases the amount of poor fit-ups is demonstrated by the joint shown in Fig. 40. When a welding operator has to fill up a gap in that particular joint, it is a very costly operation.

Many factors contribute to the extra cost and reduced quality of a poorly fitting joint. Among others, to deposit weld metal in a gap requires less amperage, frequently a smaller electrode,

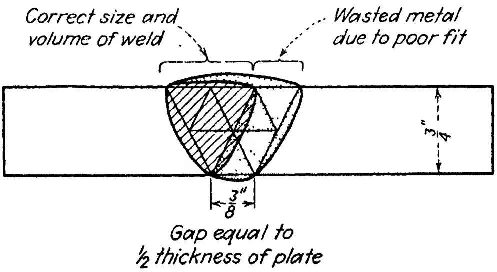


FIG. 40.—A joint with a gap equal to one-half the thickness of the thinnest plate requires more than twice the volume of weld metal to complete it, plus the costly time required to close the gap at the beginning of the weld. Such gaps in fit-up are extremely expensive when they occur, but may be prevented or corrected by correct control.

greater skill, and more beads of weld metal deposited in the locality, greater cleaning time, and a larger amount of weld metal than the joint should require.

The extra time required to close a gap (to say nothing of welding it full afterward) is frequently two or more times the length of time required to make the desired weld on that type of joint if the gap is equivalent to half or more the width of the thickness of the thinnest plate. Since labor is the most important item of cost in the deposition of weld metal, the filling of a gap is a very expensive operation.

The reduction of quality of a weld where a gap must be filled is also a significant factor because of the increased grain growth, the increased distortion, and the poor appearance of such a weld.

A last and really significant source of economy from a complete welding-control system is that of depositing the various welds on structures in the most favorable position from the

economic point of view, which is almost always the strictly down-hand position.

If the fit-up of the joints is maintained correctly and if the size of the welds is maintained properly, then the deposition of the welds in a down-hand position, or as nearly in the down-hand position as possible, makes available to the manufacturer the other elements of the maximum efficiency of weld metals deposited.

Table 1 illustrates the economy of positioning welds of various sizes for greater efficiency in deposition. Note that there is a significant reduction in cost in each successive step of positioning welds from the overhead or vertical to the completely down-hand welding position.

TABLE 1.—PERCENTAGE OF WELDING TIME SAVED BY POSITIONING VERTICAL AND HORIZONTAL-FILLET WELDS FOR DOWN-HAND WELDING

(Minutes per inch of weld based on time studies of arc time plus fatigue allowance)

Size of weld, inches	Minutes per inch of weld welded			Percentage saved by positioning	
	Vertical	Horizontal fillet	Down hand (positioned)	Vertical weld for down-hand welding	Horizontal fillet weld for down-hand welding
3/16	0.254	0.140	0.105	58.7	25.0
1/4	0.292	0.155	0.115	60.6	25.8
5/16	0.327	0.170	0.125	61.8	26.5
3/8	0.412	0.231	0.140	66.1	39.4
1/2	0.660	0.342	0.191	71.1	44.2

Whenever a welded joint may be positioned in the strictly down-hand position, it is possible to use a larger electrode, which usually costs less than the smaller electrode, will burn off in almost the same length of time, and will therefore deposit considerably more weld metal per unit of labor in making such a joint.

When a welding operator is working on the same structure regularly and is accustomed to the use of larger welding electrodes and the handling of greater amperages (and therefore faster deposition), considerable progress can be made over what is

"common practice" at the beginning of a program of weld positioning and welding control in a manufacturing organization.

There need be no sacrifice in quality of welding when a larger electrode is substituted for a smaller one in the same joint in the interests of greater speed of deposition (within reasonable limits) as is shown in Fig. 41 where the welds were deposited with

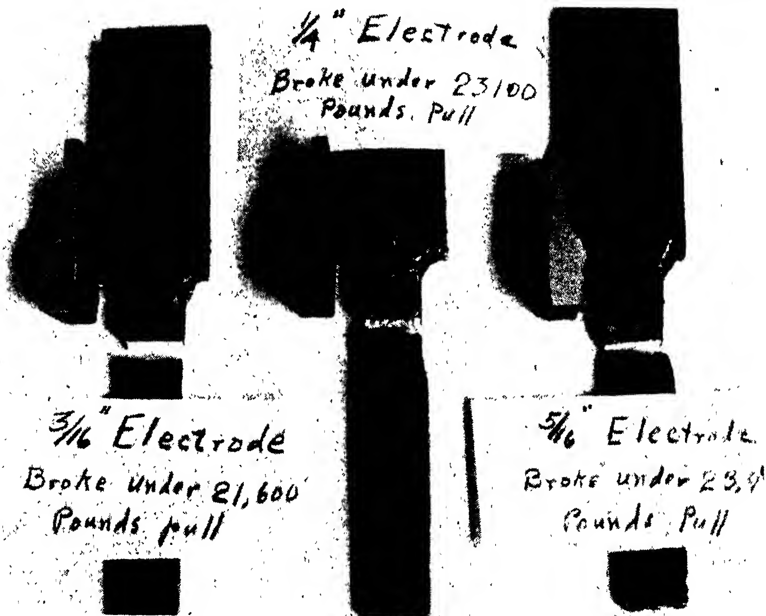


FIG. 41.—The use of large electrodes and greater welding currents (within reasonable limits) does not involve a sacrifice in welding quality and often improves the welded joint. In these three welds, made with three different sizes of electrodes at the appropriate current for each, the one made with the largest electrode was the strongest and looked the best when etched with acid in cross section. (*Courtesy of R. G. LeTourneau, Inc.*)

successively $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ in. electrodes with the appropriate amperage and speed of travel for each electrode and setting.

It is significant that the best weld obtainable on this particular joint, as shown by penetration and tensile strength of the joint, was made by the electrode that deposited the weld metal the fastest and was the least expensive.

Upon examination, many of the elements that make for real economy in arc welding as determined by size of electrode, type of electrode, position of the weld, number of passes, size of weld,

and degree of fit-up appear very often to have relatively small margins. Yet when they are accumulated, and when the waste portions or slow operations are eliminated by proper engineering control, extremely significant economy in the whole welding process may be accomplished.

Control Is Practical and Can Be Achieved.—The most hopeful and interesting fact about the establishing of complete engineering control of the factors of arc welding is that it is a process or trend in development within an organization that does not have to be accomplished overnight.

It does not require a complete conversion in the thinking of all members of an organization; nor does it require a revolutionary change in fixtures, processing, procedures, and common shop practice. Instead, it can be accomplished by a stepwise development along several lines which finally results in the possibility of establishing complete engineering control.

Probably the first and most important step is that of building setting-up and weld-positioning fixtures.

The second step, and one of the most significant, is that of improvement of fit-ups by the education of everyone who is preparing parts and by study of fixtures and templates. The most important feature of these steps is that they automatically result in considerable economy in the manufacturing of the products without the final stages of complete control and are, therefore, worth doing in themselves.

The third step is that of controlling the size of the welds and the position in which they are deposited. This may be accomplished by a system of simple welding symbols on the blueprints. Such systems, using the American Welding Society symbol code as a basis, are already established and in operation in many large organizations.

The introduction of welding symbols on the blueprints calls for an educational program and also for specialized study on the part of some member of the organization connected with the engineering department. The studies that such an individual makes and the recording of such information on the blueprints form the basis for specifications that should be placed in the hands of welding operators before they start to deposit any weld. It merely puts on a sound, scientific basis the control of the important function of joining the parts that make up the units of

machinery produced. This is entirely an engineering function and should not be expected of men without some engineering background.

After such a degree of control has been established as has been described in the foregoing paragraphs, a welding manufacturer can set up reasonable and sound manufacturing schedules, since the operations are standardized, and also establish and even predict sound cost analyses on every item of his equipment.

When all phases of the process are subject to control, scheduling, and accounting, the proper objective of specifications and of control have been accomplished. The manufacturer may then go ahead on a truly sound economic basis on whatever phase of the work he wants to start, simply by analyzing the information he has in hand.

CHAPTER V

MATERIAL CONTROL AND ARC-WELDING COSTS

An important part of the cost of all arc-welded structures is that of the raw material with which the manufacturer starts. By far the largest item of raw material for most modern users of the arc-welded method of construction is steel in the "as-rolled" condition received from the steel mills in the form of plates, bars, strips, sheets, angles, channels, and special shapes. One of the most important sources of economy in manufacture by the arc-welding process is that such raw materials can be purchased at a price which, in view of their strength and adaptability, is fundamentally cheaper than that of other materials which might be used to make the same units by other methods.

One of the most important margins of economical operation, however, depends directly on the efficiency in the use of these raw materials in the finished product. The actual cost per pound of the material in a finished product is not the exact cost per pound for which it was purchased, but rather the total cost of the amount of material that went into the finished structure plus the cost of the portions that became scrap, minus the value of such portions when sold as scrap.

In some types of arc-welded construction, a high percentage of the original raw material may be used in the finished parts, so that actually only a small percentage of it becomes scrap. In such cases, the cost per pound of the material of which the unit is made is only a small fraction above the purchased price per pound of the original material.

In many types of machinery, the best functional design, *i.e.*, the design that uses the smallest amount of material to obtain the maximum strength makes considerable use of irregular shaped parts.

An example of such an irregular shaped piece of machinery is shown in Fig. 42, a yoke structure for a large earth-moving machine. It is about 10 ft. high by 8 ft. wide by 8 ft. long over

all and is made entirely from steel plates and shapes. It will be noticed that the general shape of the unit is controlled by the irregular flame-cut parts that have been cut from plates and subsequently processed in some cases by bending or rolling to form the major portion of the structure.

Such irregular shaped parts as the side members of the scraper yoke shown in Fig. 42 tend to make the problem of 100 per cent

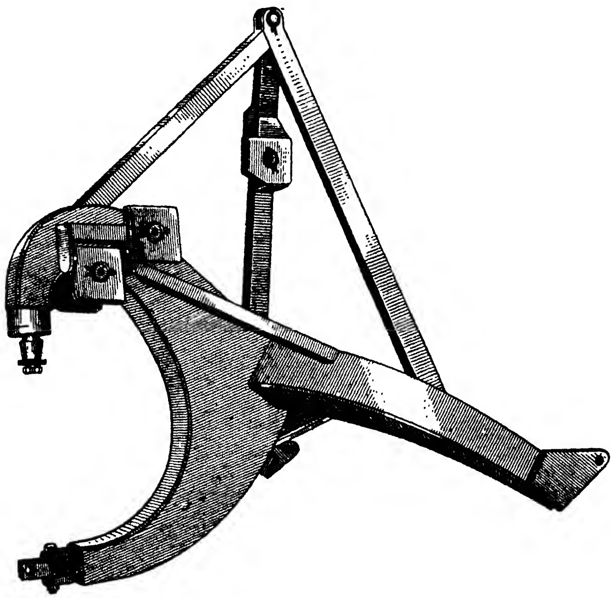


FIG. 42.—The curved stress-distributing lines of this design develop maximum functional strength with the least material. The problem of how to cut the parts without excess scrap requires study. (*Courtesy of R. G. LeTourneau, Inc.*)

utilization of original plate stock more difficult than would a more square design which would be less efficient functionally.

Since there is a tendency toward the best functional design for machinery involving a large percentage of scrap because of irregular shaped parts being cut from the original stock, an orderly study of the economics of the use of material and the effect of different percentages of scrap on the total cost of the material used is one of major importance.

Steel—Its Original Cost and Its Scrap Value.—The cost of steel as the fundamental raw material for arc-welded products is inescapable. Whatever the manufacturer pays for his original

stock of steel (and that usually depends upon whether it is alloy or plain carbon and, somewhat, upon the amount he uses), the fundamental relationship between the original cost of the material and the material cost in the finished structure is about the same.

Suppose that the original cost of the steel purchased for the production of a machine is 4 cents per pound. Even granting the high value of 1 cent per pound for scrap, a pound of the

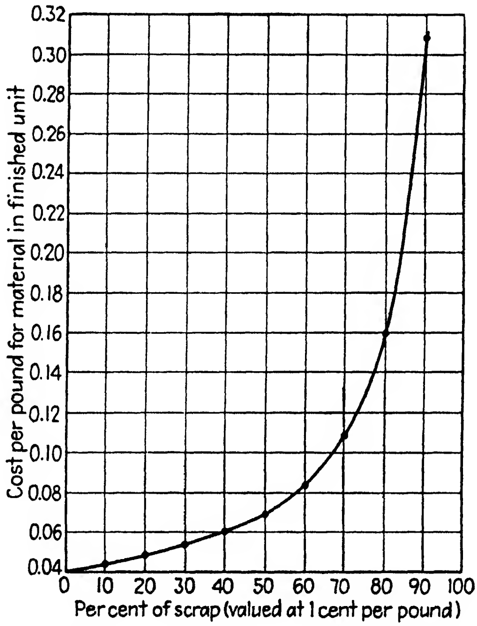


FIG. 43.—The increase in cost of material in the finished unit caused by charging scrap loss to the material used. Normally at least three-quarters of the original value of a pound of material is lost when it becomes scrap. This should be added to the cost of the material used.

original material that becomes scrap costs the manufacturer 3 cents per pound. Each pound that becomes scrap represents, therefore, a 75 per cent loss in investment. It actually represents more than a 75 per cent loss, because the cost of handling the scrap from the time it is cut from the original plate until it is delivered to the dealer must be deducted from the scrap value of 1 cent per pound; but for this study it will be considered as 1 cent per pound.

The 75 per cent reduction in original value of all scrap material has to be charged to the cost of the material in the finished

product. Therefore the percentage of scrap produced in making parts for arc-welded structures has a significant bearing upon the actual cost of the material that makes up the finished unit.

Figure 43 shows graphically the increase in cost per pound of used steel with the increase in percentage of scrap brought about by designs that use different percentages of the purchased material. The amount of scrap left after the parts have been cut from the original material, therefore, provides an effective index as to the actual cost of the material in the design; furthermore, the utilization of the remaining material after the main parts of the unit have been cut from the plate represents an important margin of economy.

There are several factors involved in the maintaining of a low percentage of scrap from the processing of steel plates or other raw material. The following are some of the most important:

1. Original design for the least scrap.
2. Careful planning in the shop to coordinate the cutting of scrap produced from parts that produce considerable scrap into other parts as soon as possible and with the least labor.
3. The machinery used for cutting parts from material that might otherwise be scrapped (sometimes the amount of material that can be rescued from scrap by a certain type of machine in a reasonable period of time goes a long way toward paying for that machine).
4. The cost of processing balanced with the value of the material, showing where it is necessary to draw the line between cutting parts from scrap (based on its value as scrap and on the original cost of the scrap material) and processing a new piece of material, perhaps of different shape and size, to get the same part.

In general, there are four sections of a manufacturing organization that are in a position to help maintain the use of material on a high level of efficiency. They are as follows:

1. Engineering department.
2. Production department (or shop steel clerk).
3. Shop processing equipment division.
4. Tool-and-die department and experimental departments.

Each will be discussed in detail in the following paragraphs.

The Designing and Engineering Department.—In the original design of a unit, the engineering department is in a position to

exert considerable influence in controlling the amount of scrap that will be left after cutting the parts for the machine from the original material. A careful study of the materials available from the source of supply and of those which are commonly used in that particular shop usually allows the engineer to select the material from which the part which he is drawing can most efficiently be cut. In this connection he should be mindful that the smaller the number of individual types of material used for a given volume of machines, the larger the volume that can be purchased, usually at some advantage in price.

Sometimes in the original design it is possible, by making a slight change in the shape of the part, to obtain the same strength and approximately the same weight and yet reduce the amount of actual cutting in the processing of the part and so to reduce the amount of scrap that is left over. It is also often possible for the engineering department, after having drawn an irregularly shaped part and knowing the type of material from which it will be cut, to plan the nesting of such parts in the original material so as to cause the least amount of cutting and produce the smallest amount of scrap and then to indicate that method of nesting on the shop working drawing of the part. Figure 44 shows such planning on the part of the engineering department. It shows an inset on the working drawing, giving the method of laying out 48-in. wide strips of plate stock for the part shown on the print so that they will nest conveniently with the smallest possible space between them even though they are irregular in shape. Figure 45 shows a working drawing of a part to be cut from bar stock on which is sketched the method of removal of the part from the original bar stock so as to cause the smallest amount of cutting and produce the smallest amount of scrap.

It does not usually take a detail draftsman long to make such layouts as shown in Figs. 44 and 45, and it is a much more positive type of control than that of expecting the shop operators to figure it out for themselves. When it is on the print, it becomes a part of the directions for cutting the piece. It then saves not only the time and effort of the shop organization in planning that phase of the work, but also the cost of the additional scrap which would result if that planning by the shop were hurriedly done or poorly executed.

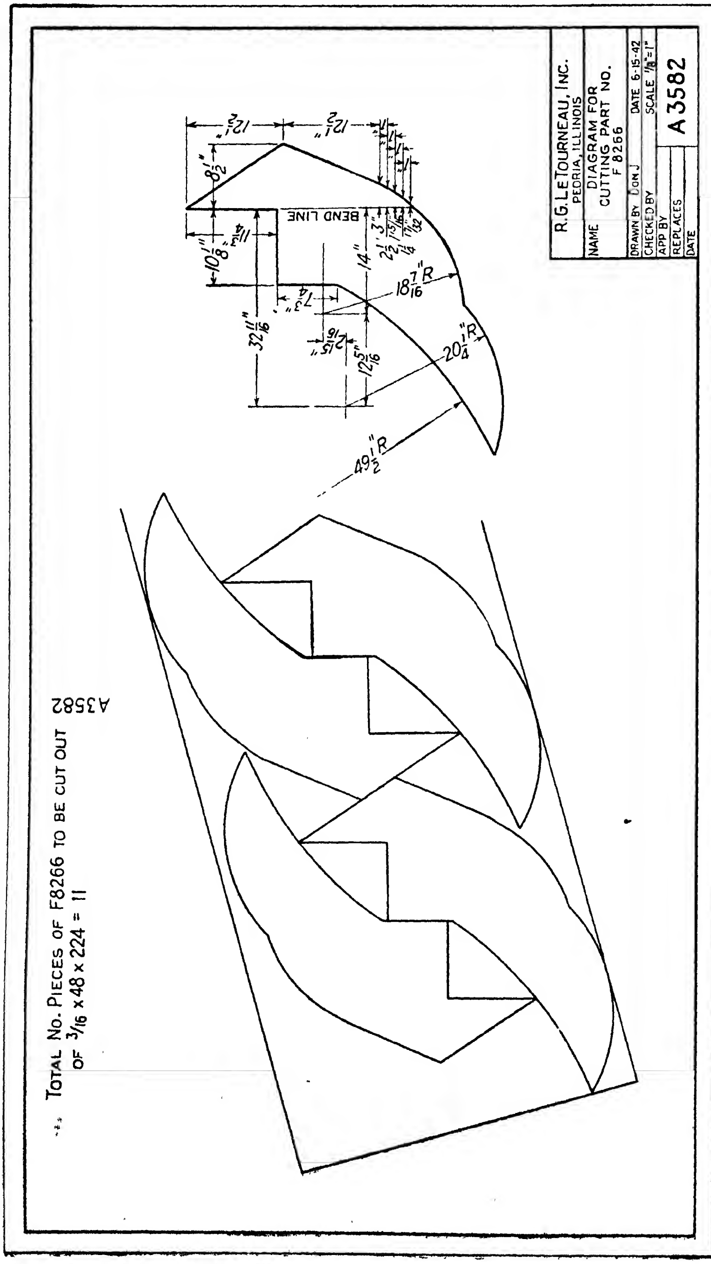


Fig. 44.—This working drawing not only shows the part, but it also shows the shop how to plan the cutting of the specified material to produce the most parts with the least scrap. (*Courtesy of R. G. LeTourneau, Inc.*)

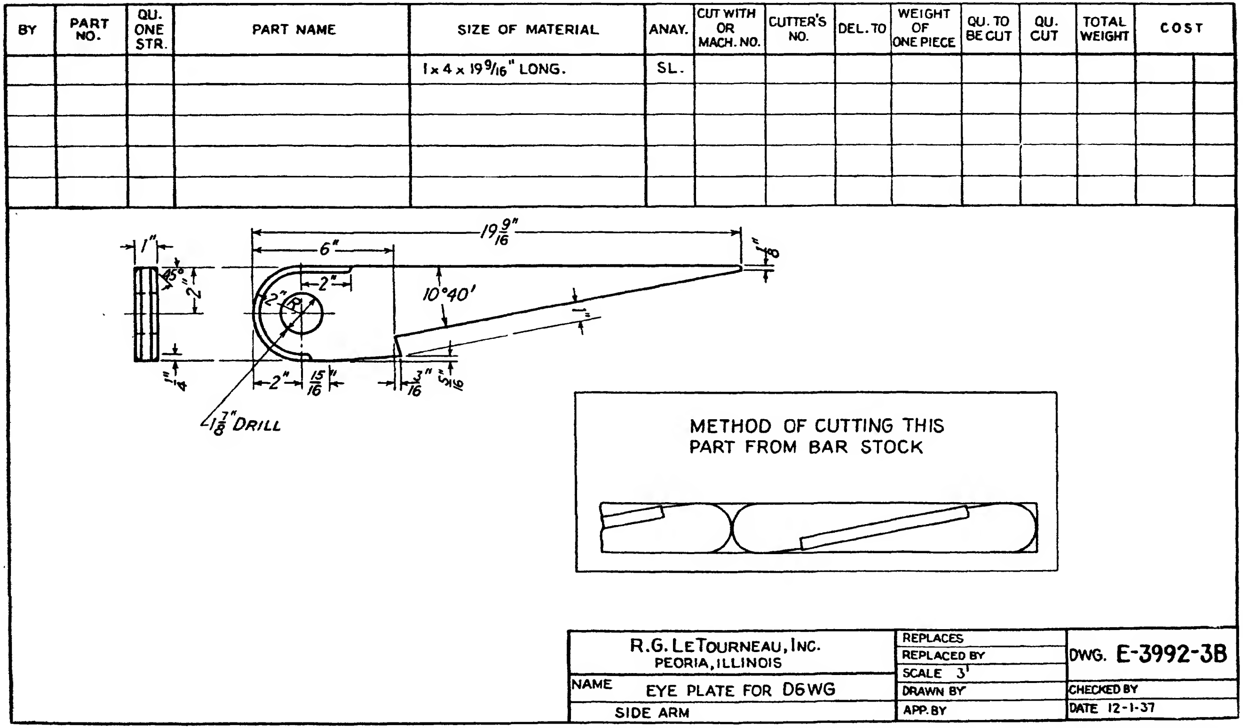


FIG. 45.—The engineering department has ensured the most efficient cutting—to make the least scrap—by specifying how this part is to be cut from the original bar stock. (*Courtesy of R. G. LeTourneau, Inc.*)

Another thing that the designing department may keep in mind and often use to advantage is the ratio of the number of one part used in a particular design to the number of another part coming from similar material. An example of this type of planning is seen in Fig. 46, which shows two doughnut-shaped parts cut from a 1-in. steel plate and one framelike part cut from the same plate. Two of the circular parts are used for every one of the frames and can be cut from the section removed from the inside of the frame. By nesting the two doughnut-like parts

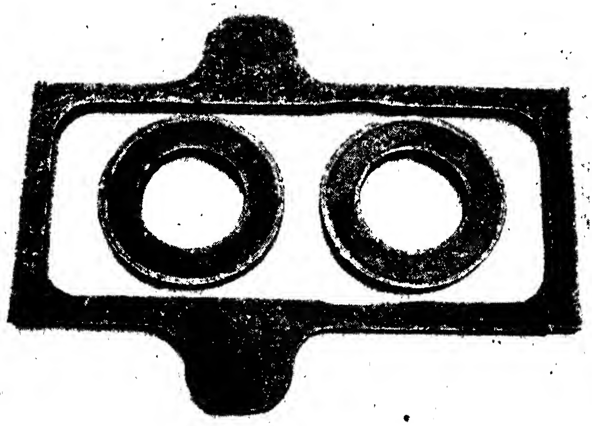


FIG. 46.—Two of the circular parts are required to every one of the framelike parts. Both types of parts have the same thickness, therefore they can be cut at the same time from the same plate leaving a sizable solid piece of scrap from which still other parts may be cut. (*Courtesy of R. G. LeTourneau, Inc.*)

close together, a piece two-thirds as large as the circular part is left from which other parts may be cut for other machines. The framelike parts are taken from plates and nest with a relatively small amount of scrap, considering the form of each of these two parts. All the parts are cut from the plate at the same time, in order to save handling the center pieces for a separate cutting.

The foregoing examples are only three of the many possible illustrations of the type of control that the engineering department can exert over the use of material when making arc-welded machinery if its members are conscious of the relative value of the material and bear in mind the shape of the scrap remaining after some parts are cut from the material. By such planning, a

large number of gussets, caps, lugs, supporting members, and even bars and strips may be cut from scrap to fit into some other machine or into some other part of the same machine. Much can be done by an alert engineering department to maintain the initial advantage the welding process provides in the use of an inexpensive raw material by designing parts so as to produce the smallest amount of scrap, and thus to maintain a high efficiency in the use of material.

The Production Department or the Shop Steel Clerk.—Another source of real economy in the use of material is the intercorrelation of the planning by the production department and the shop organization for processing in the steel-cutting department.

One effective method of attaining this type of correlation is to have an alert steel clerk, whose duties are the planning of cutting operations and the correlating of the correct production orders so as to make the best use of the material on hand. Some of the details expected of him are as follows:

1. Familiarity with all the current orders for parts in the cutting department (this involves a knowledge of the orders on hand, the orders that are to come in the near future, and the schedule on which they must be cut).
2. Detailed knowledge of the material from which parts are to be cut, including the possibility that one order of parts might be cut from the scrap of another order, rather than from new material.
3. A thorough knowledge of the methods of making all the parts on order.
4. A thorough knowledge of the scrap pile (quantities, dimensions, types of material on hand that have been left over from other jobs).
5. A thorough knowledge of the types, shapes, and general sizes of most of the parts that are produced in the shop, together with the relative quantities used, so that he can determine whether parts for regular production may be cut from scraps left over from another order.
6. The authority to decide whether scraps from the cutting of a certain order shall be placed in storage for future use or disposed of immediately.
7. A general knowledge of the cost of processing by different methods and of the original cost of the material.

An example of how an alert steel clerk may increase the economy of a steel-cutting department is seen in Fig. 47, which shows the flame cutting of a 2¼-in. plate 96 in. wide by 240 in. long. Two separate parts for two separate orders are being taken from this plate at the same cutting in order to make good use of the material and at the same time reduce the handling cost to a minimum. The large circles are being cut for one order and the smaller circles for another.

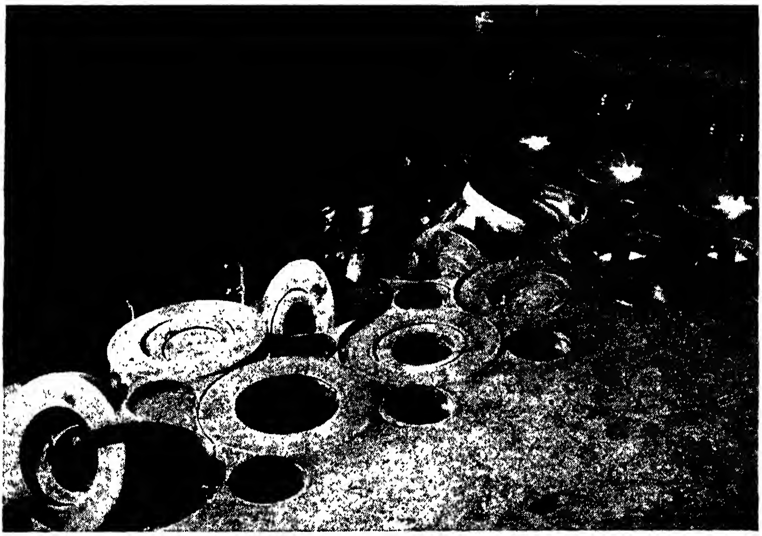


FIG. 47.—A 2¼-in. plate 96 by 240 in. being cut into two different orders of parts at the same cuting. Note the plan of nesting to use most of plate and at the same time to cut scrap into small pieces. (*Courtesy of R. G. LeTourneau, Inc.*)

The planning of the cutting sequence in this particular operation is no mean accomplishment, since the first step is to cut a small circle from the part that will be left between the large circular parts. The second is the cutting of one small circular part from the portion that will be the scrap center, cut out to make the inside diameter of the large circle. The spacing of this particular cut on the plate is important, because if an error were made in it, three of the large parts might have to be scrapped. The third step is to cut the inside diameter of the larger part. The last cuts made are the outside diameter of the large parts; they are made so that they intersect and cause the separation of

the scrap into small parts. This plan of cutting produces two of the smaller parts for one order to each of the large parts and leaves the scrap free from the parts and ready to be thrown into a bin for disposal.

A further detail in the cutting up of the plate shown in Fig. 47 is shown in Fig. 48; here the end of the plate is shown being cut into several of the small parts, since the large ones do not make

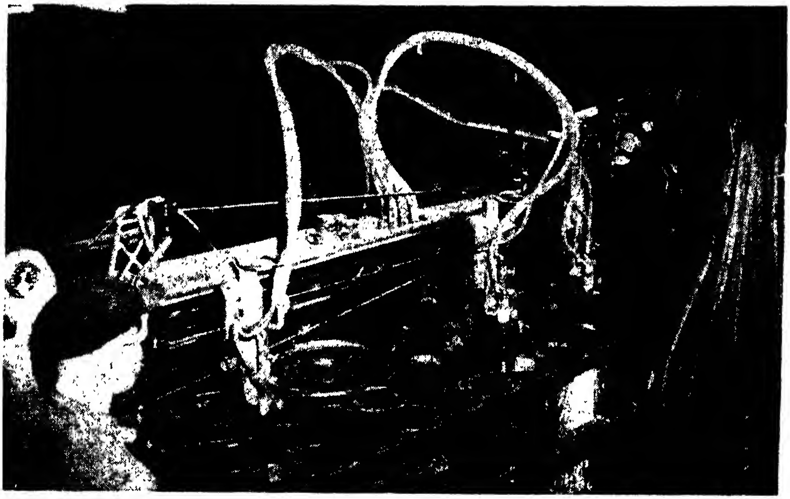


FIG. 48.—The end of the plate shown in Fig. 47 showing the part that was left over after cutting out large pieces being cut into the smaller parts. Note the portable scrap bin in the background standing near by to reduce scrap handling. (*Courtesy of R. G. LeTourneau, Inc.*)

100 per cent use of the plate. In the background is shown the type of scrap left and likewise the efficient disposition of it by simply throwing it into a portable bin which can be dumped into a car at the time of the sale of the scrap. This reduces the handling of the scrap to the minimum. Using the triple-torch mechanical flame cutter shown in the picture, two of these plates can be cut in 18 hr. of operation.

It is not always possible to cut a plate completely as shown in Figs. 47 and 48. Often there are parts remaining after an order of plate material has been cut that are large enough to make standard parts, or that may be large enough to keep on hand in anticipation of possible need later in the form of a plate-stock scrap pile. Such a plate-stock scrap pile is shown in Fig. 49

where it is piled up according to size and, in general, according to shape. Since often a repetition of orders for certain parts will bring certain regularly occurring pieces of scrap, each is piled separately and in order, as near to the flame-cutting machine as is convenient. Note the large strip in the foreground that has been trimmed slightly before being placed in the scrap pile. Such trimming and conditioning of scrap parts is a safety prac-

FIG. 49.—The pile of scraps from plate stock should be orderly, as close as possible to the flame-cutting machines, and separate sizes and shapes should be segregated. (*Courtesy of R. G. LeTourneau, Inc.*)

tice (sharp points are a definite hazard) as well as a convenience in piling. It is seldom that the pieces which are cut off in that fashion will result in additional scrap in the final cutting.

At such time as an order does come through the shop that can be cut from the leftovers in the plate scrap pile, the alert steel clerk will have the most suitable pieces brought in and will cut the order from them.

It is not uncommon, with careful planning, to keep the plate-stock scrap pile down to a relatively small size and yet to take numerous orders of parts such as shown in Fig. 50 from it in almost the same time that it would take to cut the order from new

plate stock, and for the same cost of material; for it should be borne in mind that scrap stock of any kind is worth at least as much as it cost originally until it has been sold to the scrap dealer, so far as the basic material cost is concerned.

A study of the sizes and shapes of the scrap parts left after cutting major parts in the machine from stock frequently shows

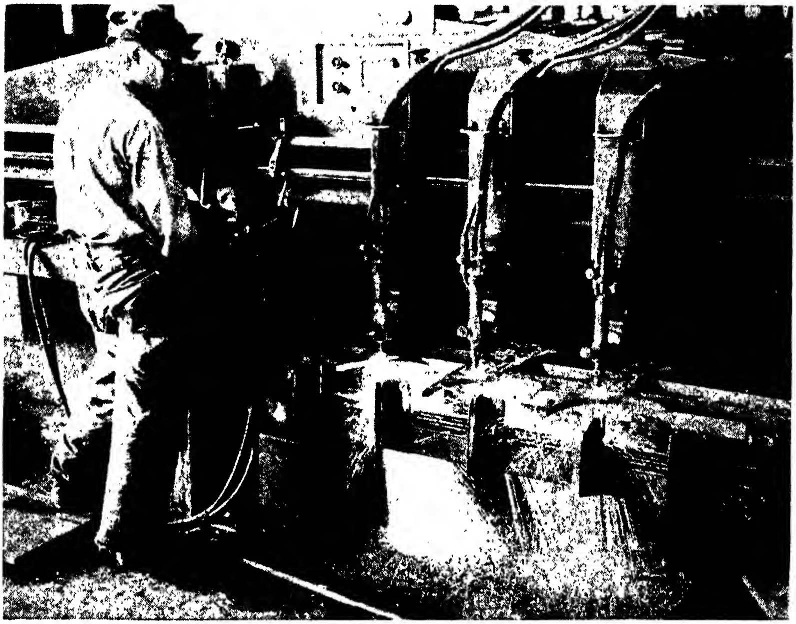


FIG. 50.—Note the small size and irregular shape of the parts being cut from these pieces of 1-in. plate scrap. Such scrap utilization reduces the total amount of scrap effectively. (*Courtesy of R. G. LeTourneau, Inc.*)

that a slight redesign or change of practice may result in considerable economy in the use of material.

Such an economy is illustrated in Fig. 51, which shows a double-ended wrench that was at one time cut from plate stock as a single part. The wrench itself nested only moderately well in the original plate material, but when the two heads were cut as separate parts with a flame-cutting unit from scrap plate stock and then welded on to a piece of bar stock that had either been flame-cut or sheared to length, much better use of material was accomplished since the heads were cut from scrap parts from other jobs. Much of the cost of welding the heads to the

wrench handle was defrayed by the difference in cost of shearing the handle part of the wrench from bar stock rather than flame cutting it.

What has been said concerning the planning and use of heavy plates and illustrated in the last few paragraphs is generally true of most of the other raw material used in the arc-welding method of making machinery. The same careful planning applies to

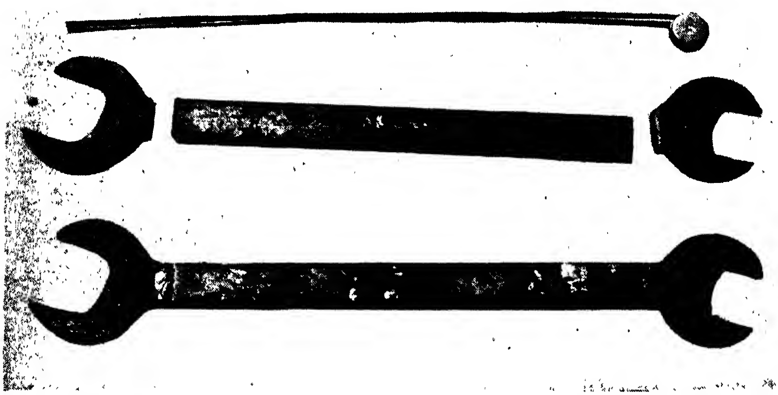


FIG. 51.—This wrench was originally made by flame-cutting the whole wrench from plate. By redesigning it, the heads were flame-cut from plate scrap, the handle was sheared from bar stock and welded to the heads, better use was made of material, and the cost of the wrench was reduced. (*Courtesy of R. G. LeTourneau, Inc.*)

thin plates as to thick ones and to angles, bar stock, channels, and any of the other shapes that are purchased. The machines used to take the parts from the raw material or the methods used may vary, but the general economy is the same.

Scrap Handling, Storage, and Cost.—The amount of space available for the storage of scrap that may later be economically cut into usable parts often plays a considerable part in the policy that can be followed by a given manufacturer in scrap-storage practice.

The scrap sections should usually be piled as close as possible to the machine that will cut parts from them and should be segregated as far as possible as to size and types. Sometimes it is possible also to build inexpensive racks for the storage of standard types of scrap that can be utilized regularly and yet that may have to be accumulated for a while before it can be cut into usable parts.

Prior to the building of storage racks a careful study should be made of the amount of time and labor spent on the storage of scrap, because the investment in time and labor may exceed the value of the parts that will be taken out of the scrap and that might possibly be taken less expensively from a different size or shape of material.

FIG. 52. - If plenty of space is available, it saves handling to pile sheared or flame-cut scrap in segregated piles, ready for cutting on short notice. (*Courtesy of R. G. LeTourneau, Inc.*)

If space is not at a premium, it is sometimes effective to pile plate-shear or flame-cut scrap in the manner shown in Fig. 52, keeping it segregated so that it is easily accessible. It is separated into different piles according to size and generally according to shape and is readily available for cutting up into smaller parts so that a minimum of handling (labor) is necessary to place it in storage and remove it. Frequently, also, thin plates that have been cut on the flame-cutting machine can be routed to such a pile after having been sheared into strips or parts by a shear such as that shown in Fig. 53, and thus save storing the irregular shaped scrap. They may then be cut into a large variety of plates, lugs, gussets, caps, and other small parts such as shown in Fig. 54.

The practice of working up scrap of all kinds as soon as it is possible into standard production parts, in order to dispose of

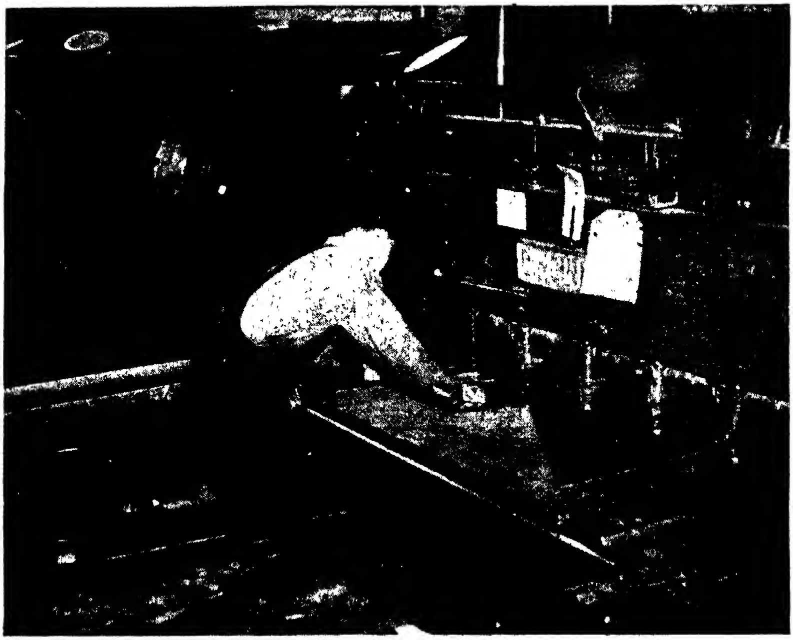


FIG. 53.—The plate shear cuts its own usable scrap into parts and also that of the flame-cutting machines which is within its cutting capacity. It is always busy and diverts much steel that might be scrapped into parts. (*Courtesy of R. G. LeTourneau, Inc.*)

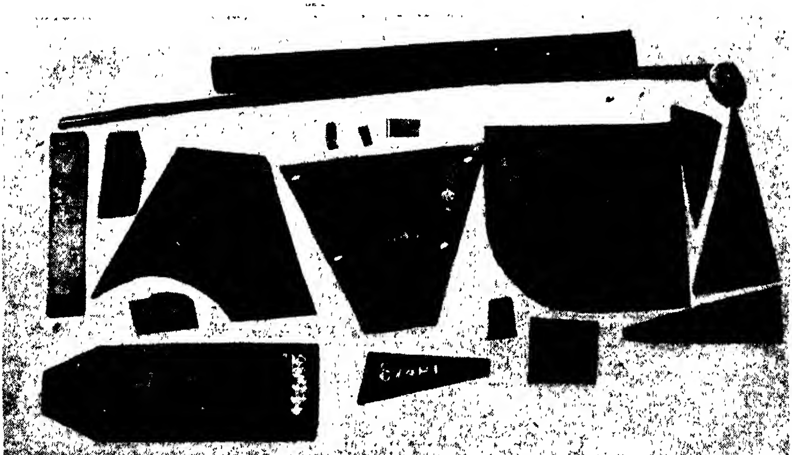


FIG. 54.—A large variety of parts such as these can be taken from scrap sections by the alert steel clerk with considerable economy. (*Courtesy of R. G. LeTourneau, Inc.*)

the irregular parts that eventually will be scrapped, is good economy. It saves space, material, labor, and the accumulation of excess scrap materials about the plant. If space is not easily available for the storage of scrap that might be cut into usable parts, it is all the more important to cut it into those parts soon after it is produced, since the accumulated overhead on space

FIG. 55.—A punch press such as this is well adapted to making small, irregular parts from thin material. The saving in labor by punching parts, plus the saving on taking the parts from scrap, may more than pay for the machine in a reasonable length of time. (*Courtesy of R. G. LeTourneau, Inc.*)

which is at a premium soon overbalances the net value of the scrap as a source of parts.

Scrap Reduction by Specialized Processing Machinery.—On relatively large-scale operations in making arc-welded machinery, the amount of parts that special blanking presses or other special machines can take from material that otherwise would be scrap sometimes goes a long way toward paying for the machine.

For example, the removal of parts from small pieces of sheared or flame-cut stock by a punch press, shown in Fig. 55, together with the other uses to which a unit of that kind may be put in a shop, sometimes justifies its purchase. The cutting of small, irregular shaped parts from thin material is often a difficult and

expensive process. Labor for their production is usually a much larger item than material if they are not made by blanking on a punch press. Parts such as shown in Fig. 56 may be punched from scrap by such a unit, and frequently they may be made at such a reduced cost over the original method of making them that the combined economy of manufacture plus the economy in use of the material justifies the existence of the machine in the plant.

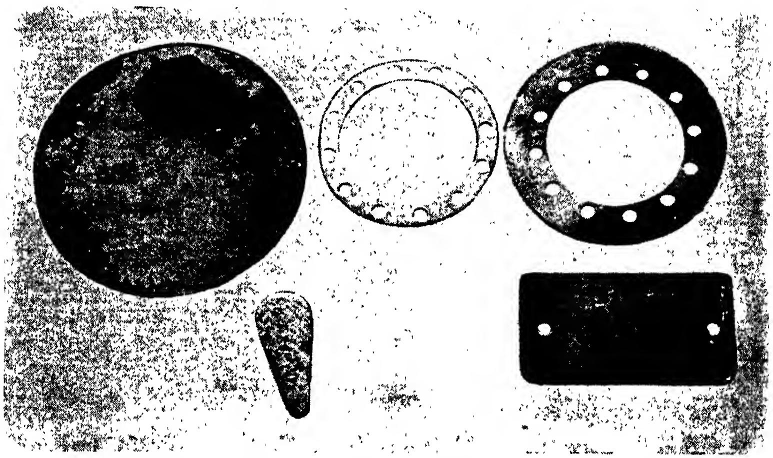


Fig. 56.—These are examples of parts punched out of plates by the punch press shown in Fig. 55. Often such parts may be taken from scrap. (*Courtesy of R. G. LeTourneau, Inc.*)

Such a machine as shown in Fig. 55 usually serves other important uses in a welding shop; *e.g.*, on a large number of sheared parts, the slight bend that results from the shearing may be taken out by the use of a properly set punch press much more economically than by hand straightening, hammering, or some other method. Such a machine can usually also be used for hot or cold forging, pressing, or forming of larger parts, with a consequent reduction of welding, since such forming usually makes a part from one large piece of steel rather than as a welded structure from several parts, each of which must be cut, set up, and tacked together.

An example of how even a large piece of machinery may sometimes be used in relatively large operations in the welding method of manufacturing is exemplified by the press shown in Fig. 57. This 600-ton mechanical press is used on a mass-production basis

to make a large variety of parts which originally were made by somewhat more expensive processing.

The parts shown in Fig. 58, for example, are hot blanked from ⅝-in. special alloy steel by the 600-ton press and are usually taken from scrap. As indicated by the size of the 6-in. rule

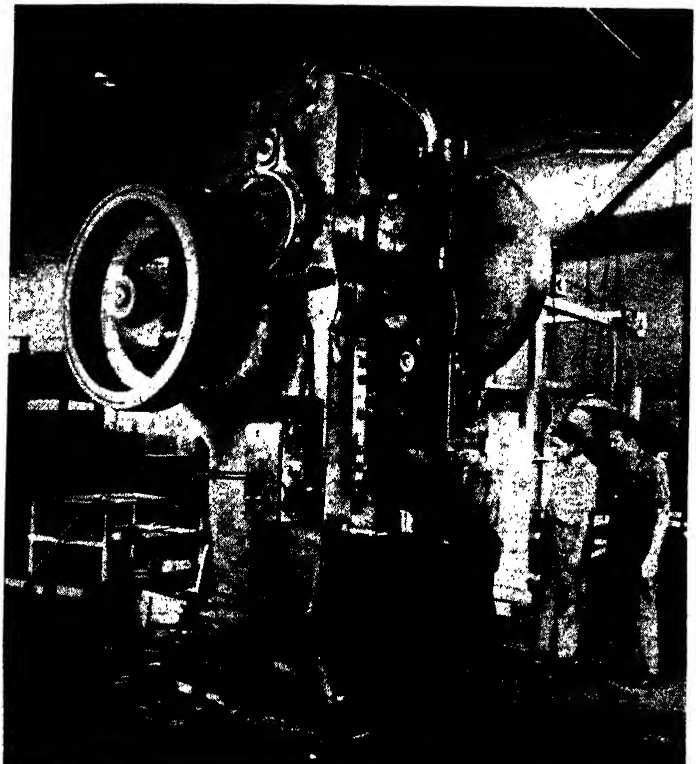


Fig. 57.—This 600-ton mechanical press pays for part of its cost by hot or cold blanking of parts from scrap plate. (*Courtesy of R. G. LeTourneau, Inc.*)

included in the picture, the weight of each of these parts made from ⅝-in. plate amounts to a sizable factor when they are made in lots of several thousand. Compared wth the cost of flame-cutting from scrap or from original plate, the difference in manufacturing them by punching them with the big press goes a long way toward paying for the press. Also, the difference in machining on such a part as the upper left piece, which later

acts as a cam, is less when it is made by punching than by flame-cutting.

The parts shown in Fig 59 are another example of the use of the large press. A ¾-in. plate is cut to length and taken to the

FIG. 58.—These parts are punched from ⅝-in. alloy scrap stock by the 600-to mechanical press for less than it costs to flame-cut them. (*Courtesy of R. G LeTourneau, Inc.*)

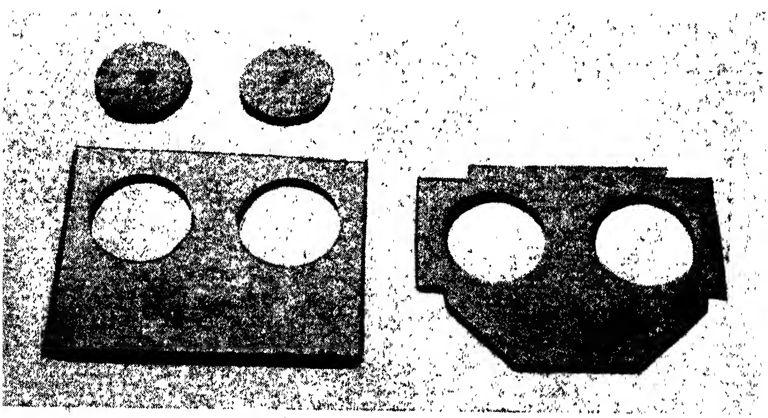


FIG. 59.—The two slugs 4⅛ in. in diameter are punched from this plate in one punching by the large mechanical press shown in Fig. 57. (*Courtesy of R. G. LeTourneau, Inc.*)

press where the two slugs 4⅛ in. in diameter are punched out in one punching. The remaining plate is then processed further by flame-cutting the corners out and drilling them to finish the part originally taken from the large plate.

Because the $4\frac{1}{8}$-in. slugs are punched out rather than flame-cut, enough material is left in the slugs so that they can then be

FIG. 60.—The slug shown in Fig. 59 on the left is hot forged into the adjusting nut blank in the center and then machined into the nut shown on the right. (*Courtesy of R. G. LeTourneau, Inc.*)

FIG. 61.—The finished nut made from the $4\frac{1}{8}$-in. slug punched from the top plate of this structure is screwed back into the threaded hole from which it was originally punched, giving almost 100 per cent use of material. (*Courtesy of R. G. LeTourneau, Inc.*)

hot forged under the same large mechanical press to form an adjusting nut, shown at the right in Fig. 60. After completion of the nut and of the original part from which it was punched,

the nut is then returned and screwed into the top of the completed structure as shown in Fig. 61. This allows almost perfect use of material and uses the slug that was punched out of the plate originally to take the place of a part that was previously made by the more expensive method of sawing it from bar stock and machining it to size, which involved the waste of considerable material.

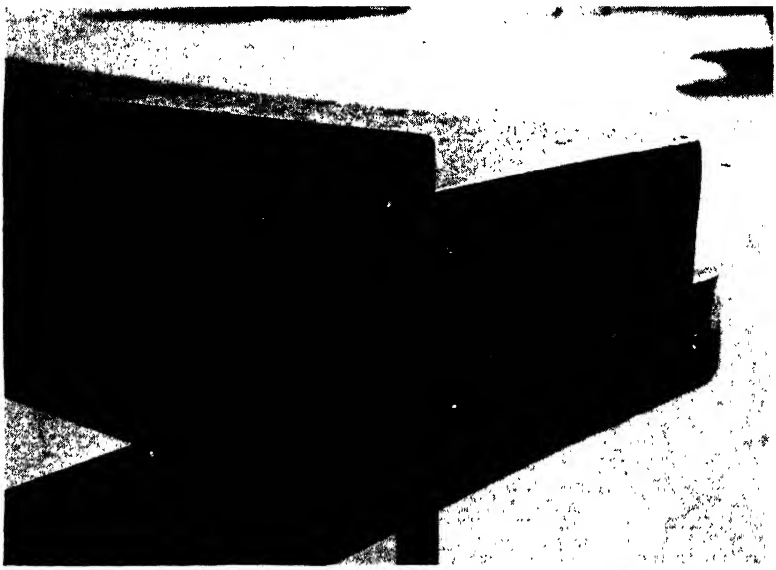


Fig. 62.—The end cuts from large parts such as this 14- by 24-in. billet often come in handy for dies, special blocks, or other parts requiring large pieces of solid steel. (*Courtesy of R. G. LeTourneau, Inc.*)

These are only a few examples of how scrap may be utilized for the production of parts and of how the utilization of scrap may sometimes present a margin of economy that justifies considerable changes in equipment and in the processing of the part.

Use of Scrap in Special Fixtures, Jigs, Dies, and Experimental Units.—Another very important source of economy is the use of scrap materials in the manufacture of experimental machinery, jigs, fixtures, dies, and ordinary factory equipment.

When an experimental unit is being made, small parts and odd shapes, only a few of which are needed for the unit, can often be taken from the accumulated material in the scrap piles. Here again, the alert steel clerk who knows his scrap pile and who

plans the cutting of all the parts for experimental machines or shop equipment units can frequently produce the parts without having to cut into new material at all.

For this reason, it is frequently good economy to make a special point of saving the end cut from such large parts as the

FIG. 63.—Scrap pieces such as these, ranging from 3 to 8 in. in thickness do not take up much space compared with their weight, yet often supply much needed die and jig part material. (*Courtesy of R. G. LeTourneau, Inc.*)

14-by-24-in. billet shown in Fig. 62, which has been flame-cut to make a special part. The large piece left in the end cut contains a considerable weight of solid steel which may be cut into smaller parts in the manufacture of dies, lathe chucks, special blocks, or other such parts. Such a scrap pile as is shown in Fig. 63, including pieces of 3- to 8-in. plate from which the parts for which the plates were originally purchased have been cut,

FIG. 64.—Scrap plate, bar, and shape stock was the largest source of material used in making these press dies. (*Courtesy of R. G. LeTourneau, Inc.*)

FIG. 65.—When the toolroom needed material to make this toolholding setup, the steel clerk had pieces of scrap that did the job. (*Courtesy of R. G. LeTourneau, Inc.*)

often supplies useful pieces for other special purposes. One important point about such material sources is that usually the whole weight of the raw material is charged to the original job in the cost-accounting practice, and the cost of the material for the dies or whatever else is made from the resulting scrap pieces may be accounted for at scrap value.

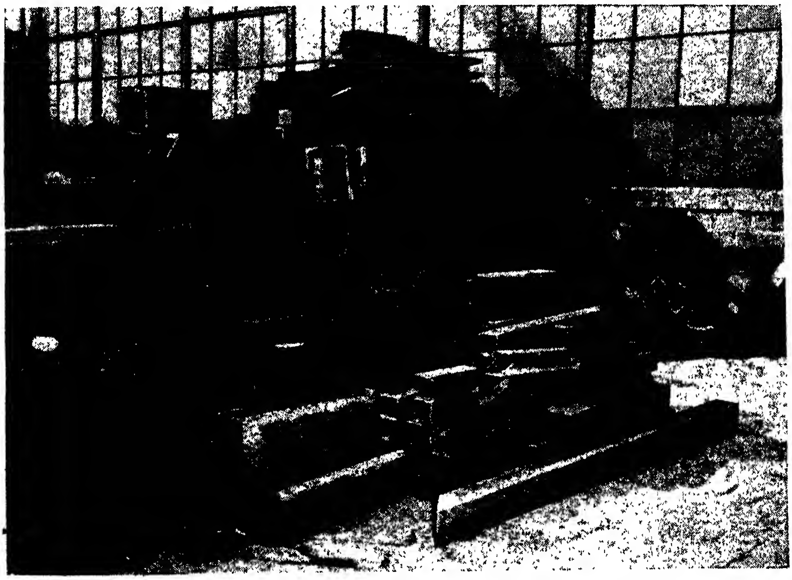


FIG. 66.—This pile of end cuts from regular production orders furnished not only short pieces for regular products, but also parts for shop equipment as shown in Fig. 67. (*Courtesy of R. G. LeTourneau, Inc.*)

Figure 64 shows a group of large, heavy press dies, much of the material for which was taken from the scrap pile, either the heavy-plate scrap, light-plate scrap, or bar-stock scrap. The use of scrap materials in such dies as these, combined with the modern method of flame cutting from plates, grinding, chamfering, and hard facing, reduces the cost of such dies to a minimum. This constitutes a further margin for the use of machines requiring such dies with greater over-all economy.

The resourceful toolroom foreman also makes good use of the scrap pile for the manufacture of such jigs and fixtures and toolholding framework as may be used in the machine shop. The toolholder shown in Fig. 65, made from a piece of thick plate

stock, was flame-cut from a piece of scrap and charged to the toolroom at scrap value. It serves the function for which it was made very satisfactorily; and though not a structure of beauty, it is very economical.

The advantage of having a scrap pile of angles, channels, and special shapes, such as shown in Fig. 66, is illustrated by an examination of the machine base shown in Fig. 67. The base

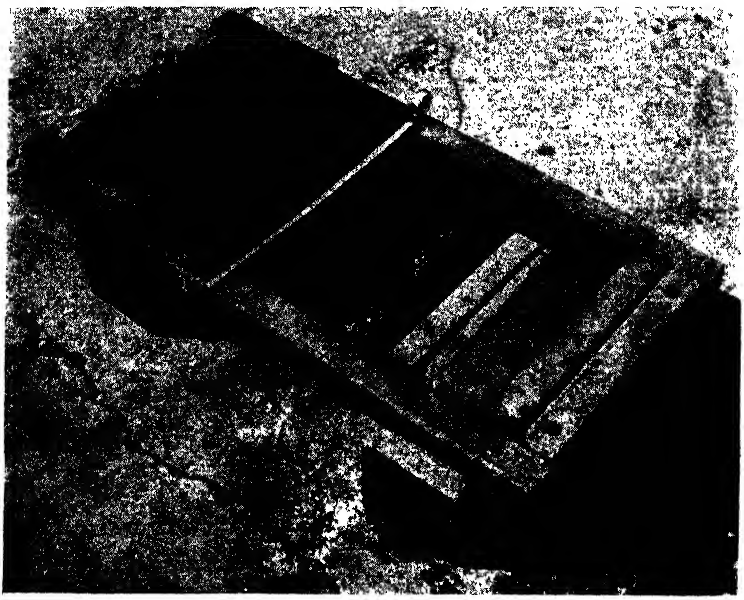


FIG. 67.—All but the side members for this shop-equipment machine base were taken from the scrap box beam and bar stock piles with a marked economy of labor and material. (*Courtesy of R. G. LeTourneau, Inc.*)

was made for a factory-equipment installation where utility was the main consideration. Aside from the two side members, all the rest of it was taken from scrap plate, angles, and bars. In making this structure, it probably took considerably less time to get sections from the scrap stock pile and cut them to the correct size than it would have taken to get new sections of raw material from the steel clerk and cut the necessary parts. By using the scrap end cuts from previous "production" orders, the cost of the material for the base was only its scrap value.

The angles were simply welded into box sections, flame-cut to length, and welded together to make the necessary base. The

bolt holes in the plates and bars at the upper left hand of the base were drilled and tapped before the parts were welded together.

This simple base made from scrap material illustrates only one of the many opportunities for the use of scrap material by the alert experimental department and maintenance department in making special shop equipment.

In even a relatively small shop, if every opportunity is taken to use scrap material for such units, the total cost of material used in the manufacture of salable equipment or of equipment used in the factory is reduced considerably, because it is not necessary to take the fundamental depreciation in material value that results from purchasing raw material at a price of about 4 cents per pound and selling what is left, after all the usable part has been cut out, at 75 per cent less.

CHAPTER VI

CONTROL OF FLAME CUTTING OF PARTS FOR ARC WELDING

Without the development of flame cutting of steel on a mass-production basis, the use of arc welding for mass production of machinery and equipment, as we know it today, could hardly have developed.

The exacting demands of duplication and accuracy of reproduction involved in the mass production of arc-welded machines are met economically by the mechanical flame-cutting machine. For the production of the large, complex curved or irregular plates so evident in many modern designs, the flame-shape-cutting machine is practical. By using a template that can be set up in a short time, shapes may be cut from plate, one to four at a time, in as large a quantity as is desired. Each is essentially an exact duplicate of the other. The flame-cut edge is sufficiently smooth and clean to fit accurately and can be welded without further processing. No other economical means of producing such parts for welding is known. Machinable tolerances can be held regularly if the templates, machine, and workman's care are all properly applied to the job.

Another important relationship of mechanical flame cutting to the arc-welded fabrication process is the speed with which irregularly shaped parts may be cut from plate as compared with any other means of making them. In producing individual machines, or the first experimental machine, parts may be laid out and drawn on the drafting board and then traced with a shape cutter from a temporary template.

The wide range of capacity of shape cutters makes the process readily adaptable to almost any arc-welded fabrication that uses steel plate. Figure 68 shows two parts cut from ⅛-in. steel plate, two others cut from 2½-in. plate, and still another pair cut from 4-in. plate. The actual limits of the capacity of the machines is less than ⅛ in. minimum plate thickness to

over 10 in. thick. The cut through the 14- by 24-in. billet shown in Fig. 62 was made by a flame-cutting machine. Pieces as thin as 20 gauge have been cut by stack cutting, placing many plates one on top of the other, clamping them together, and flame-cutting them. Figure 69 shows the cutting of the small cap plates shown in Fig. 68. Thirteen ⅛-in. plates are clamped together, tack-welded, and cut as if they were one plate.

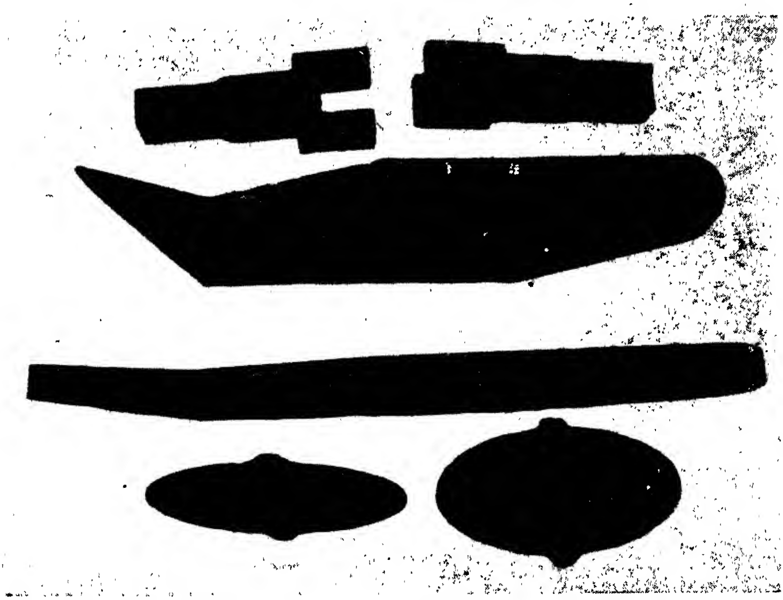


FIG. 68.—Plates from 20 gauge to 10-in. thick can be flame-cut mechanically. (*Courtesy of R. G. LeTourneau, Inc.*)

Parts may be cut whose dimensions range from only a few inches up to 96 by 360 in., or longer if the flame-cutting machine's ways are longer than 30 ft.

The adaptability of flame cutting as a quick and economical means of producing a special part, such as the sprocket cut from the templates shown in Fig. 70, is often important as a time and money saver. Such parts could be pressed (blanked) out of plate, but a great number of the parts could be flame-cut for the cost of a blanking die. The blanking out of parts with a press is naturally limited to the ratio of press capacity to plate thickness, and some designs would require heavier presses than many manufacturers have available.

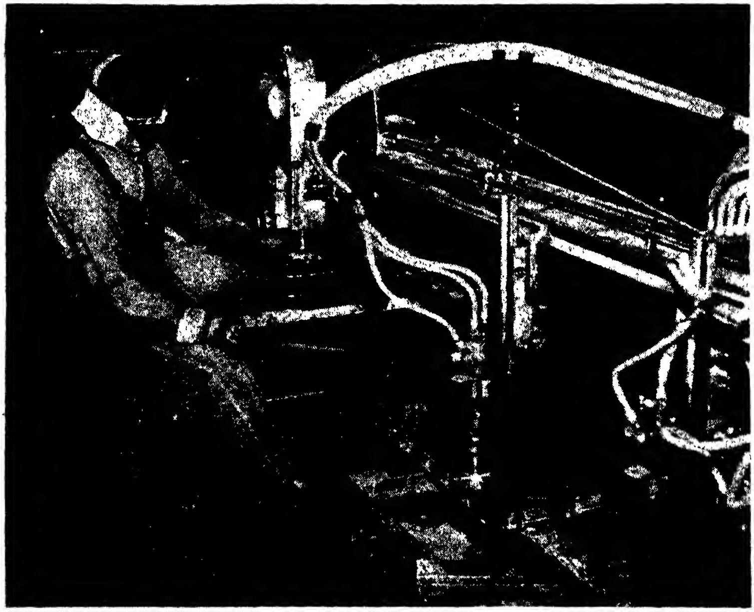


Fig. 69.—Stack cutting irregularly shaped parts from thin plates. (*Courtesy of R. G. LeTourneau, Inc.*)

Fig. 70.—Parts may quickly be cut from steel plate to make an emergency repair. The cardboard template on the left is a temporary template to be traced; the template on the right produces the gear shown above it and is more nearly permanent. (*Courtesy of R. G. LeTourneau, Inc.*)

Figure 71 illustrates the application of flame cutting to parts that are irregular and are formed or shaped after cutting. Many parts could be made from bar stock and fabricated by the building up of parts sheared, flame-cut, or sawed from bar stock, but the savings made by flame cutting an irregular shape from plate and pressing it to the desired form often eliminates enough welding to make it a profitable process.

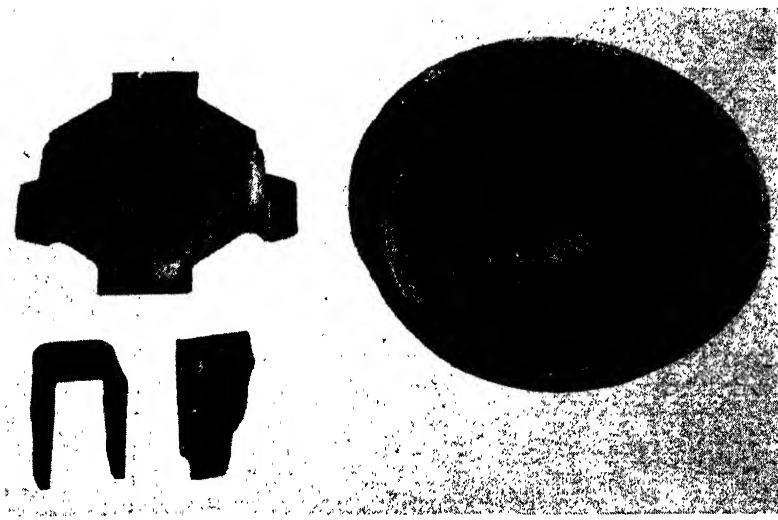


FIG. 71.—Parts cut for pressing or shaping. The bowl was a 38-in. disk cut from 1½-in. plate and pressed hot. The other parts are irregular shapes cut from ¾-in. plate. (*Courtesy of R. G. LeTourneau, Inc.*)

Types and Applications of Mechanical Flame-cutting Machines.—There are three general types of mechanical flame cutters, each of which is designed for, and more or less limited to, a certain class of work. They are (1) the multiple-flame shape-cutting machine, (2) the magnetic type flame cutter, and (3) the portable (or tractor) flame cutter. The function and application of each type of machine follows.

1. *The Multiple-flame Shape-cutting Machine.*—Machines such as those shown in Fig. 72 are by far the most important production flame-cutting machines for arc welding. The size of the pieces they can cut is limited only by the length of the ways on which the torches are mounted and the longitudinal travel of the main carriage on the rails. The machines shown in Fig. 72

will accommodate a 96- by 240-in. plate ranging from 1/8 up to 10 in. in thickness if necessary.

One template and two, three, or four (usually three) torches are used. The time required to cut three pieces, each exactly alike for all practical purposes, is about the same as for one, and the smoothness and uniformity of the cut is much superior to

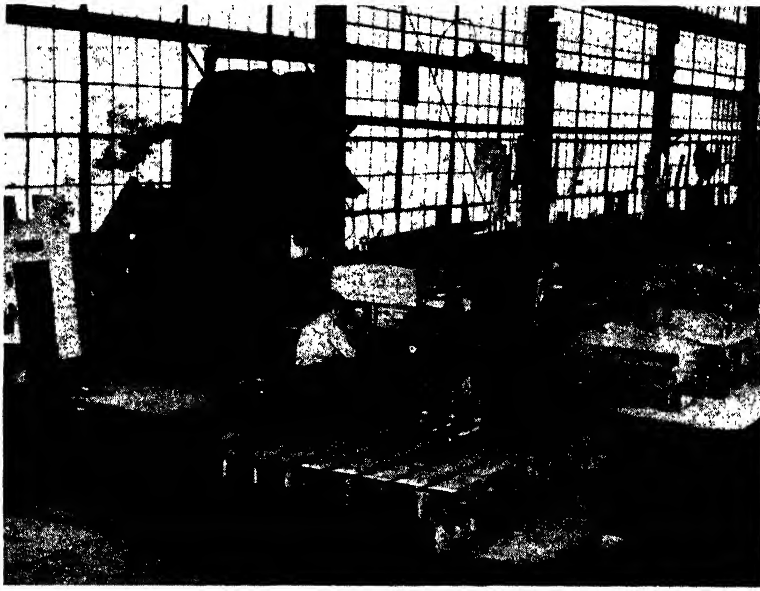


FIG. 72.—Three multiple-flame shape-cutting machines in production. Templates used by machines such as these must be accurate in size and form for consistent production of cut parts on a quantity basis. (*Courtesy of R. G. LeTourneau, Inc.*)

that of the same cuts made by a skillful hand-torch operator. These are the real production flame-cutting tools, and the other two types are of much less importance, although each has a useful place in a large welding shop.

2. *The Magnetic Flame-cutting Machine.*—The magnetic flame-cutting machine such as is shown in Fig. 73 is a small, stationary, single-torch machine much less important than the multiple-torch machine, yet one that is adaptable to a wide variety of jobs. The machine operates on the principle of a torch mounted on a flexible arm that allows the torch to be guided by a motor-driven, magnetized drive wheel which follows a steel template. This

construction results in great freedom of manipulation of the torch, but also limits the size of the piece that can be cut to the length of the sweep of the arm.

The variety of cuts that can be made on this type of machine is illustrated by Fig. 74, which shows a few representative cuts on regular production parts. It is unexcelled as a tool for the

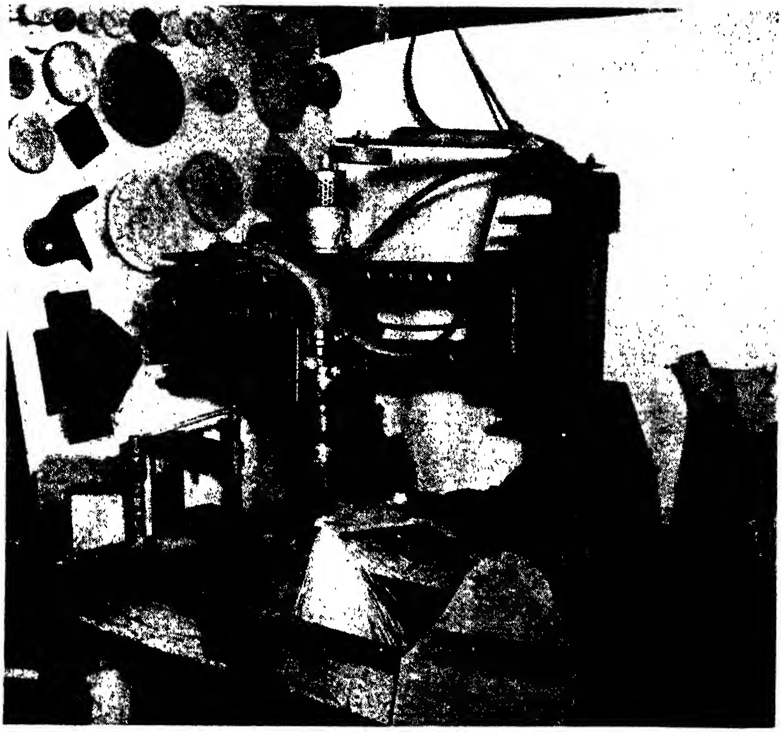


FIG. 73.—A magnetic flame cutter in operation. A few templates may be seen in the background. (*Courtesy of R. G. LeTourneau, Inc.*)

cutting of notches in plates, rounding or beveling off corners, cutting slots or holes out of parts, and making uneven cuts on parts that are first sawed, sheared, or punched and that need some additional cutting done on them which cannot be done by the machine that originally cut the part without costly machining or expensive tools and dies.

One of the advantages of using the magnetic flame cutter to make the finishing cuts on parts is that in the case of most of the

pieces the operator can place the part in the machine and start the flame to cutting, and while it is automatically finishing the cut on the piece, he can remove the slag from the piece cut previously and pile it on a transportation tray. This procedure saves the slagging time over the hand-torch method of making

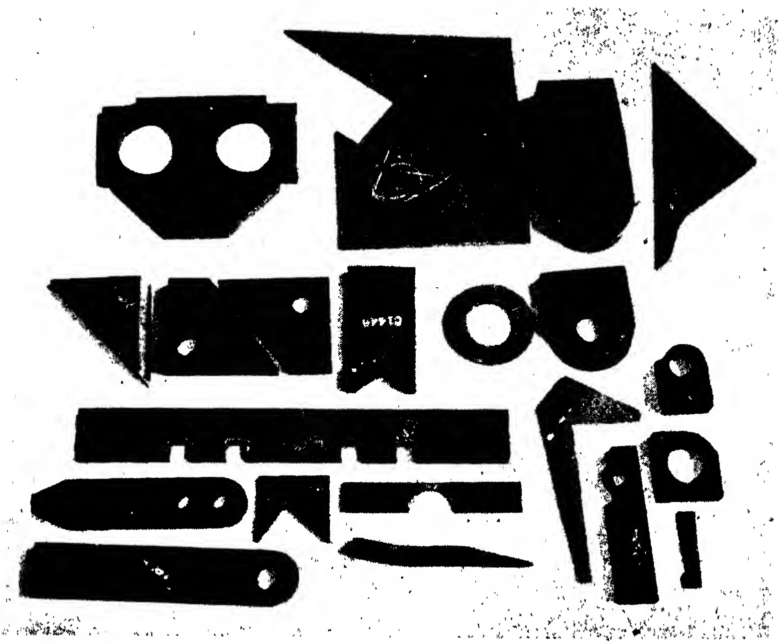


FIG. 74.—An endless variety of notches, radii, irregular cuts, and finishing cuts can be made profitably with a magnetic flame cutter on sheared or sawed parts. Most of the holes in these parts are drilled or punched. (*Courtesy of R. G. LeTourneau, Inc.*)

such cuts and avoids delay in the flow of material to and from the machine.

Frequently, a saving in the original cutting of the part on the saw or shear can be accomplished by cutting parts double as shown in Fig. 75 and then making the finishing flame cut serve the purpose of cutting the pieces apart. Many parts nest partially, so that only the width of the kerf has to be added to the double cut in order to accomplish a saving of nearly half the first cutting cost, as well as a substantial saving of material. Naturally the handling is also reduced.

Bevel cuts that are shorter than the sweep of the arm of this machine can be made, as illustrated by the parts shown in Figure

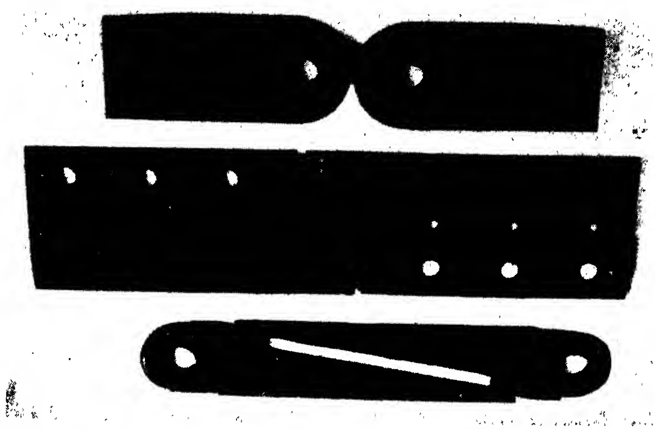


FIG. 75.—Irregularly ended parts from bar stock may often be cut double, the flame cuts serving to part them. (*Courtesy of R. G. LeTourneau, Inc.*)

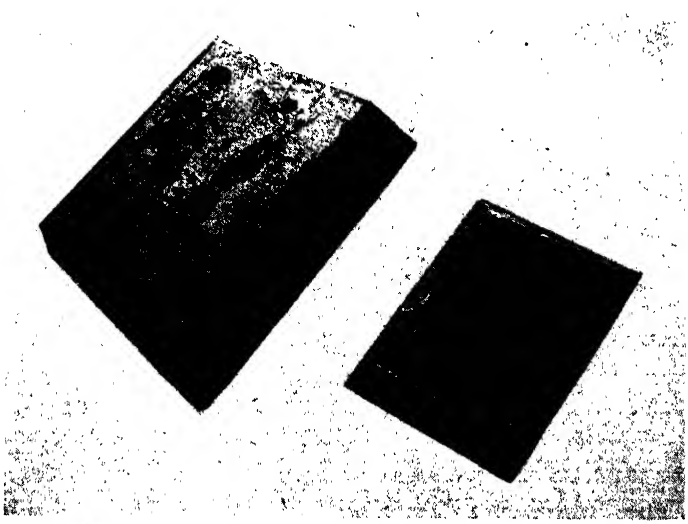


FIG. 76.—Mechanically flame-cut bevels ensure uniformity, smoothness, and accuracy on chamfered or beveled parts. Both of these plates are 1½-in. thick. (*Courtesy of R. G. LeTourneau, Inc.*)

76. Both of the parts shown are cut from 1½-in. steel plate, and then the bevels are cut on the magnetic flame cutter. A

much more uniform and economical cut can be made mechanically than by hand in scarfing or beveling such parts.

3. *The Portable (or Tractor) Flame Cutter.*—A portable flame cutter such as shown in Fig. 77 is readily adapted to long flame-ripping jobs where a long cut on a straight line is necessary. It operates on a rail for such jobs and has the advantages of a

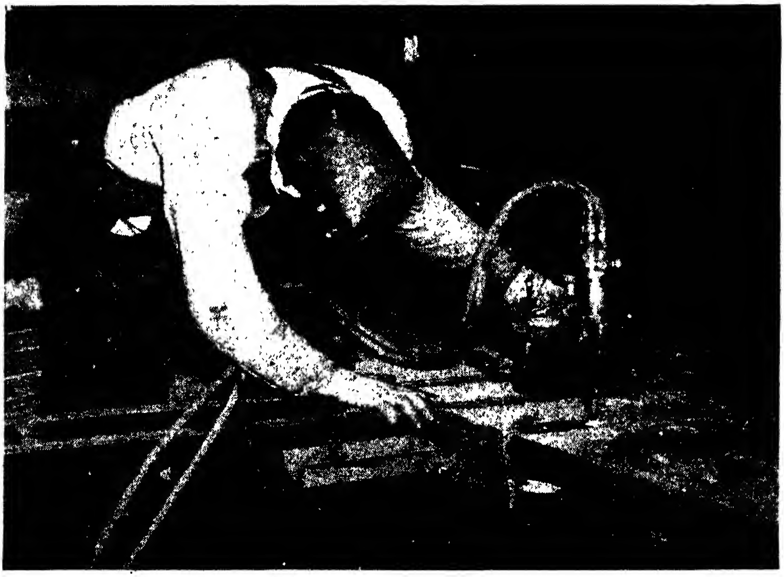


FIG. 77.—A portable flame-cutting unit on the job. (*Courtesy of R. G. LeTourneau, Inc.*)

mechanical regularity of cut and uniformity of production. Long beveled members and long scarf cuts for welding can be made in the same manner as a long straight cut by tilting the torch of the tractor flame cutter to the desired angle.

The other general use for the portable machine is that of making small localized cuts, either along straight lines or with a radius rod, on heavy plates. The small machine can be taken to the large thick plate, such as the 2½- by 20- by 99-in. plate shown in Figure 77. The cut can be made without removing and transporting the whole plate to the cutting machine and then having to rehaul and repile the plates after the small piece of the desired size is removed.

Importance of Flame-cutting Control.—The quality of workmanship and the degree of accuracy of the flame cutting play

an important part in the final appearance of the unit, and also have a significant bearing on the cost of building the unit.

In the first place, almost all modern arc-welded machinery receives the general shape of its outline from the flame-cut parts, as illustrated in Fig. 78 which shows a main body structure of a modern all-welded earth-moving machine. The black parts in this phantom view are the ones that have been cut by the flame-cutting method and may be seen to form the major outlining parts of the unit. A high degree of accuracy and good workman-

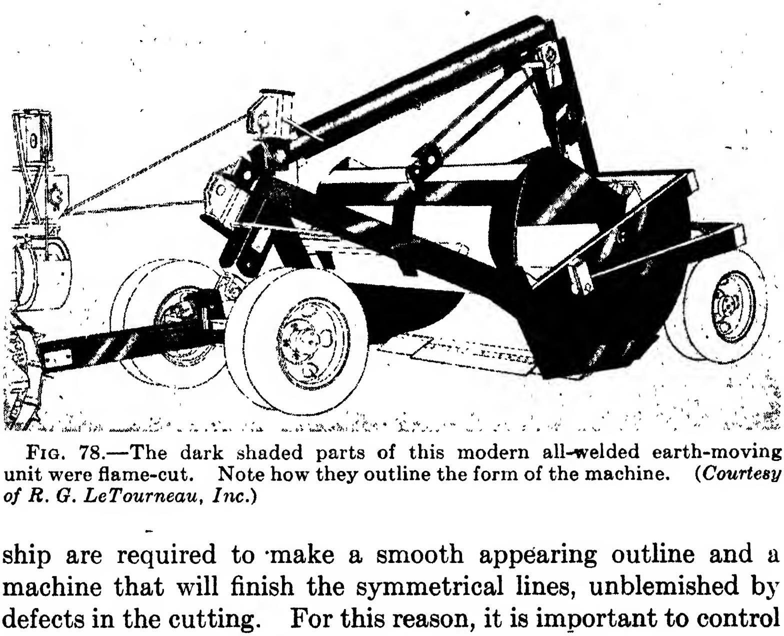


FIG. 78.—The dark shaded parts of this modern all-welded earth-moving unit were flame-cut. Note how they outline the form of the machine. (*Courtesy of R. G. LeTourneau, Inc.*)

ship are required to make a smooth appearing outline and a machine that will finish the symmetrical lines, unblemished by defects in the cutting. For this reason, it is important to control the mechanics of the flame-cutting process, as well as the over-all accuracy of the shaping of the part.

A second important factor, that of the cost of the completed unit, is considerably affected by the accuracy and workmanship of flame cutting, simply because the arc-welding process is one of joining edges, rather than of lapping them. When the edges are lapped, close accuracy of dimensions is not necessary in the cutting of the parts. In the setting up of the arc-welded structure, however, if the edges do not come together in proper relationship there is always a heavy expense in the additional work

of cutting the parts to fit at the time of setup, or a very expensive process of filling up the gaps with weld metal. In the average welded joint, if there is a gap equivalent to half the thickness of the thinnest plate, the time required to fill the gap with weld metal is more than two and one-half times that required to weld the joints if the fit-up were what it should be.

By means of careful control and thorough workmanship, parts may be cut mechanically or by hand, with the flame-cutting

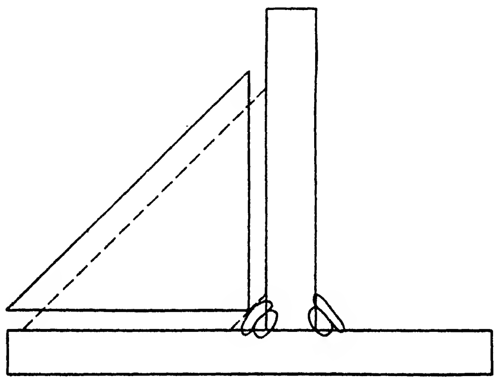


FIG. 79.—Note the fit-up problem caused when the corner is left on a gusset that fits up to a weld (solid lines); and note the fit-up when the corner is cut off. These corners should be cut off when the part is originally cut. (*Courtesy of R. G. LeTourneau, Inc.*)

process, to a high degree of accuracy. One of the most important factors in accurate cutting is that of completely laying out and studying each part and its relationship to the others. Gussets or reinforcements such as those shown in Fig. 79 and bearing blocks that are set into box structures of welded construction should be studied with special care in order to get the corners cut to fit the contours of welds or other slight irregularities in the place where the parts will have to fit. Note how the three-cornered gusset sets up to the weld without gap *if the corner is properly beveled.* The corner has been removed so that the part will fit the contour of a weld (or a natural fillet in the structural shape of the part) against which the gusset or block fits in order to save having to cut the corner off to fit as the setup of the structure of which the gusset is a part is being made, or in order to avoid welding the part in place, leaving a gap on one or more sides of the piece in the structure. These rounded, or beveled,

corners and other small but important details of the shaping of parts by flame-cutting can be built into the original template or design of the part and can be made to fit the place in the machine where they will finally be used with a high degree of accuracy without further cutting or fitting at the time of setup.

Control of the Equipment, Materials, and Process of Flame Cutting.—General observations should be made about the care and use of the mechanical devices used for flame cutting in order to assure good workmanship and efficient operation.

Probably first among these is that the units, whether they are hand-operated cutting torches or mechanical flame-cutting machines, should be clean. The operating parts should be kept working smoothly by means of cleaning and proper lubrication; and all valves, driving mechanisms, etc., should be free of irregularities, dirt, or maladjustments that tend to interfere with the smoothest operation of which the machine is capable. Any slight hesitation in the operation of the machine, whether it is the opening of a valve or the uniformity or speed of travel, will cause a defect in the parts being cut. Careful servicing and regular careful cleaning of the machine by those who operate it go a long way toward assuring high-grade workmanship in the flame cutting of parts.

The selection of the proper tip for the cutting of any part and the correct cleaning and use of the tip also have an important bearing on the width of the kerf, the contour of the flame-cut surface, and the speed with which the cutting job can be done. Almost all the major producers of flame-cutting equipment have bulletins with specific directions and diagrams that describe the proper selection, the correct use, and the most effective means of cleaning flame-cutting torch tips. Such bulletins may almost always be had for the asking and should always be in the hands of both the foreman and the operator of the flame-cutting department.

Another really important matter of control, both from the standpoint of initial costs and materials and that of the speed and efficiency of the cutting process, is that of the regulation of the oxygen and gas used in the flame-cutting process.

The amount of oxygen used in flame cutting, especially on heavy materials, constitutes a major raw-material cost in the modern arc-welding manufacturing plant. It is not uncommon

to find oxygen pressures of 60 or 70 lb. per sq. in., or even more, being used for flame-cutting operations that would operate more efficiently from the standpoint of the quality of the cutting job done and as efficiently from the standpoint of speed if they were performed with a pressure of only 30 or 40 lb. per sq. in. In addition, cuts made with lower pressures are easier to slag after cutting.

One effective means for controlling the pressure used in the large mass-production flame-cutting operations is to have a single manifold from which the oxygen is distributed to the various cutting operations and a single valve that will automatically regulate the pressure to the desired number of pounds per square inch, beyond the control of the individual machine operator. These can be set by the foreman to meet the requirements of the job and are then not subject to individual adjustment or to the possibility of getting out of adjustment. If the primary source of oxygen is cut to a pressure of 30 or 40 lb. per sq. in., the possibility of using an excess of pressure on any cutting job is eliminated. Pressure adjustments less than the maximum at the manifold can be obtained by the pressure gauge at the individual machine.

As in the case of cutting tips and their uses, there are also charts available for the asking from almost all producers of flame-cutting equipment that give cutting speeds and the pressures of oxygen required for certain types of jobs. These should be consulted by the foreman of the cutting department and be constantly on hand in the department. At times it is possible to reduce the total number of cubic feet of oxygen used per month in a large cutting establishment to two-thirds or even less by establishing effective control of the oxygen pressures being used. Since oxygen is a relatively expensive raw material, the conservation of one-third or one-half of the quantity being used is a definitely important factor of economy.

Templates and Their Use in Mechanical Flame Cutting.—One of the most important factors in mechanical flame cutting with units such as the ones shown in Fig. 72 is the use of templates that control the outline of the pattern cut by the flame. For the cutting of regular shapes such as circles, many of the multiple-head flame-cutting units now on the market will automatically describe a circle of almost any given dimensions and thereby

eliminate the cost and the care of special templates. The same is true of long cuts which are straight, whether they make a diagonal cut across the plate or a straight one; a simple long straightedge may be used which automatically guides the torch along the line.

Wherever it is possible to use either a simple circular cut or a long straight cut which can be made with a straightedge, the cutting operation may be made much simpler and usually more accurate.

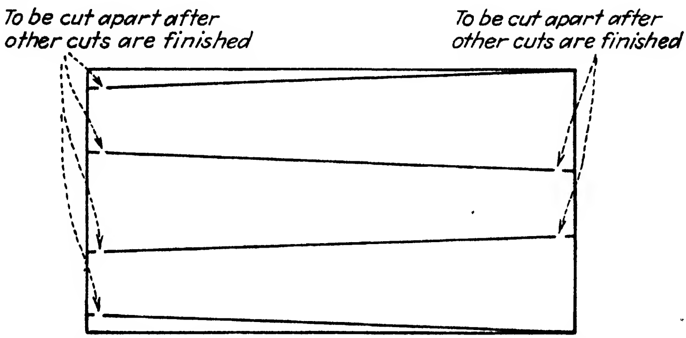


FIG. 80.—By leaving long narrow strips tacked together by skipping a fraction of an inch of cut as shown here, and then cutting them apart after the last long cut is finished, sidewise distortion is held to almost nothing. This applies also to semicircular cuts.

In making long cuts, such as ripping long and narrow pieces from a plate, the problem of distortion because of the heat applied to one side of the cut is often the cause of serious misfits. Experience has shown that if the ends of the cuts are left uncut for the last few inches (or even a fraction of an inch) as shown diagrammatically in Fig. 80, and then a hand torch or one of the torches from the multiple flame cutter is used after cooling to cut the pieces apart, most of the distortion will be eliminated. The reason this method eliminates distortion seems to be that the parts are not cut apart and allowed to spring before the counterbalancing effect of the cut that is made on the other side of the part has had a chance to balance the stress from the heating on each side of the strip.

Much of the steel that is used in the ordinary manufacturing of equipment or machinery can be cut cold. There are some parts, however, cut from high-carbon steel, that may be cut much more easily when preheated to 400 or 600°F. In such flame-cutting

hot, it is necessary to make careful calculations of the amount of expansion the heat has caused, so that when the parts are cool they will not be found to be shorter than they should be. The expansion of steel is stated to be 0.00000636 in. per deg. F.[1] This does not seem to be much, but it means that if a 10-ft. piece of steel is heated to 1000°F. it will gain, in round figures,

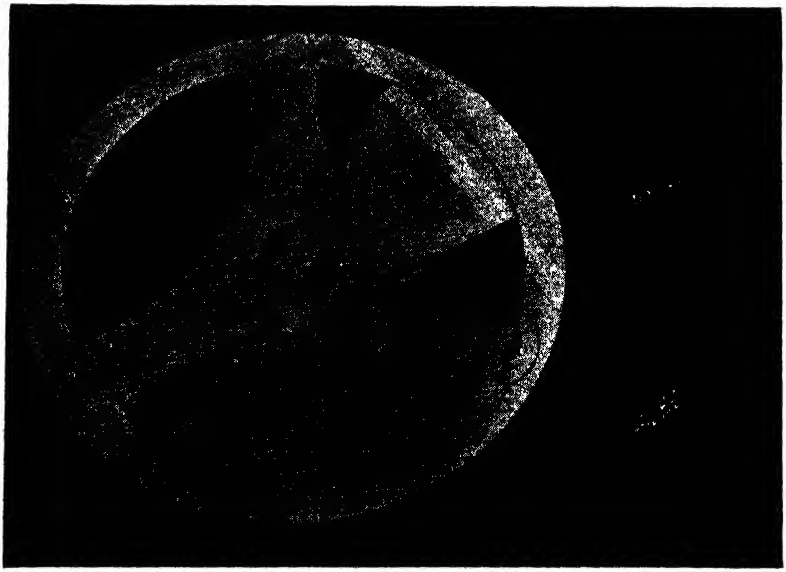


FIG. 81.—Three types of templates for mass-production flame cutting. The large one on the left is cardboard and is used to trace cuts with the multiple flame-cutting machine for only a few pieces, *i.e.*, 10 to 30 or 40. The upper right one is for large numbers of pieces mechanically cut, and the lower right one is a special metal template for cutting pieces by hand. (*Courtesy of R. G. LeTourneau, Inc.*)

¾ in. in length. That amounts to over 1/16 in. per ft. per 1000°F. Since this is a constant value per degree of heat, 500°F. would cause only half the lengthening of a piece that 1000°F. would cause.

A large number of the parts that are being used in modern arc-welding design are irregular in shape. These irregularly shaped parts require the use of templates of some sort to allow their reproduction on a mass-production basis so that each part is a

[1] OBERG and JONES, "Machinery's Handbook," 10th ed., p. 1580, The Industrial Press, New York, 1940.

faithful reproduction of the originally specified part. There are many forms of such templates, three examples of which are shown in the group in Fig. 81.

Each of the three shown in Fig. 81 lends itself to a different type of use in the production of flame-cut parts. The heavy cardboard template may be used for a relatively small number of parts that may be traced on the multiple-torch mechanical flame-cutting machine or may be used for the marking and laying out of parts to be cut with a hand torch.

The wooden template with the metal lining is used for the production of large numbers of parts that are regular production items not subject to frequent changes. This is the part that guides the guide-wheel mechanism on the mechanical flame-cutting unit for the production of the largest portion of the flame cuts in the modern factory.

The steel template lends itself best to the laying out by hand of large parts that are cut on a production basis by hand where the problem of spacing certain cuts with reference to the other parts on the plate is very important. Such a steel template as shown in Fig. 81 greatly reduces the amount of time required for the layout of a part prior to flame-cutting it by hand. It is a great convenience to the operator who can place the rigid and permanent steel template on the plate to be cut, locate it from some one starting point, and proceed to mark it out with no fear of its becoming bent, moved, shrunken, or otherwise out of adjustment.

Probably the two most important requirements in the manufacture of templates for flame cutting is that they be (1) sufficiently durable to maintain their shape and form for as long as they are required for that job, or for a reasonable life; and (2) that they make a completely accurate reproduction of the parts they are to produce, with the appropriate adjustment made for such compensations for the shape of the template as may be needed to make a perfect part.

Template making is one phase of the engineering for flame cutting and arc welding where additional care and effort expended in order to get perfect accuracy and minute detail may pay large dividends. Hurriedly made templates, or templates that are made without proper regard for the minute details of the requirements of the job, often cost tremendous amounts of money in

fitting up parts that do not fit properly or filling up gaps caused by poorly fitting parts.

By the same token, corrections on templates that are found to be inaccurate should be made carefully whenever an irregularity shows up that is constant in the fit-up of parts. Permanent templates may be relatively expensive to make and yet may be much less expensive to make over or correct than the time and

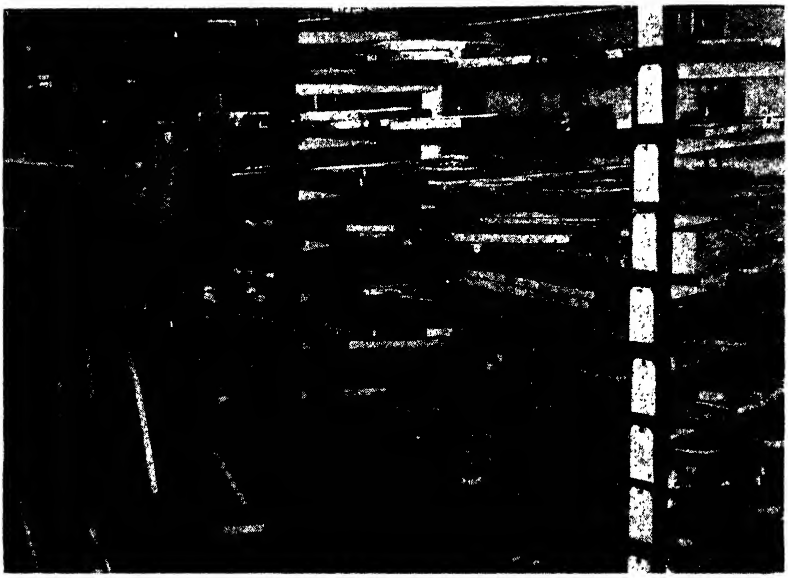


FIG. 82.—Templates for flame cutting represent a large investment in engineering and labor and control large expenditures of labor and material. They should be stored carefully and protected from mishandling or loss. Racks such as these prevent damage to templates in storage and also save time in finding them when needed. (*Courtesy of R. G. LeTourneau, Inc.*)

labor required to correct the misfits that they may cause if they are defective.

Storage of Flame-cutting Templates.—One of the most difficult problems confronting the manufacturer of flame-cut parts is that of the correct storage of templates. Templates for some types of machinery may be large and of a shape that makes it impossible to put them in cabinets or large lockers. Figure 82 shows one solution to the template-storage problem in a cutting department, where large templates of steel or wood are used.

A rack on which templates may be hung without fear of their being bent out of shape, having things dropped on them, or

otherwise being damaged is a good investment. If each template has its part number legibly painted upon it, it can be quickly and easily taken from the rack and restored to its proper place after use. Since templates are the primary pattern for the cutting of valuable materials and controlling large amounts of workmanship, it is important that they be properly cared for. A small and apparently insignificant warpage or bending of an original template may cause a costly defect in a large order of parts, when it is used.

The storage of small templates, and of paper templates, can usually be effectively accomplished by the use of large cabinets with shallow drawers, wherein the templates may be placed by template number corresponding to the part number. It is important that the drawers of such a storage cabinet be shallow so that there will not be excessive handling of the templates in order to find the one that is wanted at the time it is to be used. Excessive handling of heavy cardboard templates often bends their points, and may even tear them; and after they have been used for a few times, they may not reproduce with the degree of accuracy that is expected of them.

Control of Hand Cutting of Plates and Shapes.—In modern welding practice, there are many parts that have small minor bevels on them that can hardly be cut at one time with an automatic multiple flame-cutting machine. These parts frequently must be cut by hand with an ordinary flame-cutting torch. Also, large numbers of shapes are used such as angles, box sections, pipes, channels, I beams, H beams, and T beams that do not lend themselves to mechanical flame cutting.

One of the most effective devices for uniform hand cutting both for straight cuts and straight bevels and for small irregularly shaped parts is that of the cutting template. For straight cuts or straight bevels, a small straightedge such as is being used in Fig. 83 by the cutter is an effective means of steadying his hand and helping him to produce quick, accurate, and uniform cuts.

The same thing can be accomplished by making a small plug-like fixture for circular cuts or for irregularly shaped cuts. Such a fixture is shown in use in Fig. 84 and is shown with the cut parts in Fig. 85. It should consist of a framelike skeleton that is light enough to be handled easily and to be positioned quickly

and accurately; it should have on it stops that can be set against some starting point on the piece and should have an unbroken continuity of form so that the torch may be moved around it at a uniform speed and without any bumps or jogs. Such a fixture eliminates the process of marking and laying out by hand prior to the cutting operation and also allows the cutter to produce

FIG. 83.—The straightedge being used by this cutter is a tool used on almost 100 per cent of his straight cuts, whether beveling or upright cutting. Such a tool greatly reduces operator fatigue and improves smoothness of cuts as well as speed in locating torch and starting cuts. (*Courtesy of R. G. LeTourneau, Inc.*)

more uniform and smooth cuts without the added strain of carefully guiding his cut freehand around the pattern that he is making.

The manufacture and use of templates on such flame-cut parts as are shown in Fig. 86, *viz.*, long beveled cuts or irregular cuts and pipes or box sections or channels, require considerable study on the part of the template maker to begin with and considerable skill on the part of the flame cutter who lays the template on the stock and marks it out and follows it to make the cut.

Either heavy cardboard or, in the case of a more permanent fixture for a greater production item, a metal template that may be placed around the part can be used to lay out such cuts on the parts shown in Fig. 86. Careful study must be made of the compensation for the width of the soapstone or other marking material that is used in drawing around such templates by the cutter or the layout man. Also, care must be used in marking

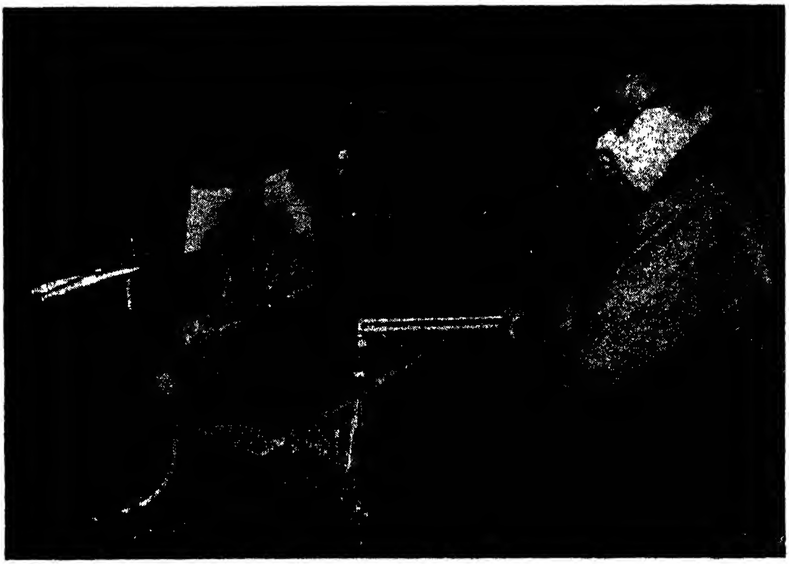


FIG. 84.—The special template fixture being used here is a means of making accurate flame cuts on complex parts without previously laying out the cuts; it also gives the cutting operator a guide to steady and control his cuts with a minimum of fatigue and lost motion (see Fig. 85). *(Courtesy of R. G. LeTourneau, Inc.)*

such templates if they are cardboard so as not to wear down the side of the template or ravel it and thereby cause inaccuracy by wearing out part of the template. Whenever possible, the template used should either fold completely around the member, or at least (in the case of box sections or channels) lie on three sides of it so that the template does not have to be moved and repositioned on the part during the laying-out process. It is easy to make small errors in the repositioning and matching up of a template to finish a layout job on a channel or box beam if it cannot be done in one operation. Figure 87 shows how a straightedge should be used to make the cuts shown in Fig. 86.

In template making for the cutting of shapes such as channels and box beams, careful indication on the template as to just where

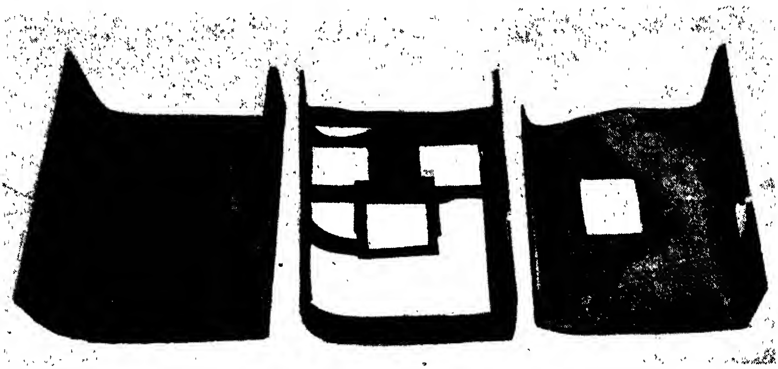


FIG. 85.—The template fixture shown in Fig. 84 is here shown with the uncut blank for the part on the left and the finished part on the right. (*Courtesy of R. G. LeTourneau, Inc.*)

FIG. 86.—The laying out of cuts such as these on box-beams, pipes, or shapes requires careful manipulation of accurate templates as well as carefully studied cutting technique. (*Courtesy of R. G. LeTourneau, Inc.*)

cuts shall be made with reference to the removal of portions of the web is important. Skill and considerable care are required

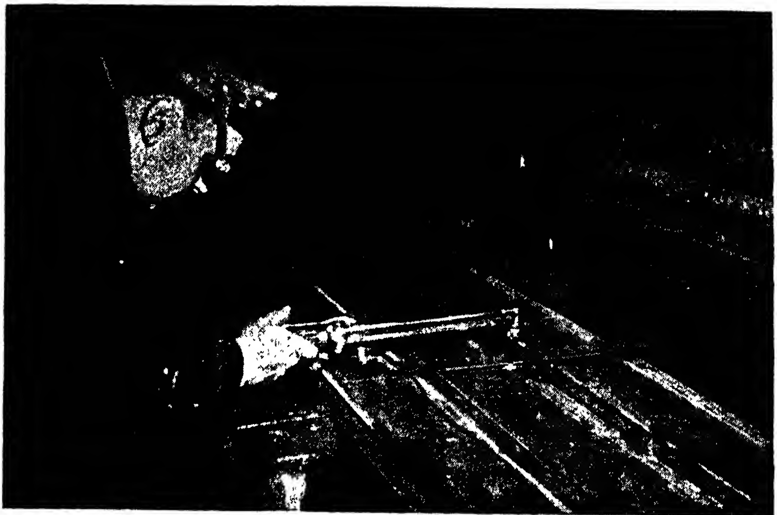


FIG. 87.—The straightedge is a great timesaver and accuracy-of-cut improver in cutting box-beams or channels. It should be used for all straight cuts on parts such as shown here and in Figs. 86 and 88 in order to assure good cuts and accurate fit-up of parts. (*Courtesy of R. G. LeTourneau, Inc.*)

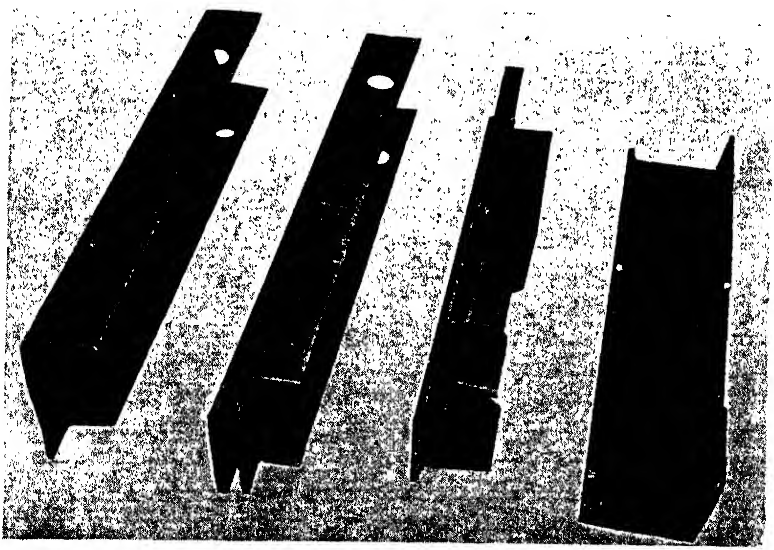


FIG. 88.—The cut and bent portions of the web on the lower end of the channel on the left are shown unbent second from left. These portions require careful layout and skillful cutting of webs and fillets which are naturally rolled into the shape to allow correct fit-up after bending. A straightedge should be used on cuts for parts such as these. (*Courtesy of R. G. LeTourneau, Inc.*)

to make parts such as are shown in Fig. 88 so that when they are heated and bent the webs will join properly for a weld joint. The responsibility for making these joints fit properly belongs to the maker of the templates; for if the template is made properly, it will show exactly where the cuts are to be made. If such a template is used, it is up to the operator who lays out and who makes the flame cut to follow the lines faithfully and to visualize properly the way in which the part is going to be bent in order to make parts fit together.

The production of flame-cut parts, whether on a mass-production basis or on the basis of a single part, is a process that requires considerable care on the part of the flame cutter himself. Care must be exercised all the way through the process from the positioning of the part on the machine, or on the stand on which it will be cut, so that it will be level and accessible to the flame and so that when the flame cuts through it will not be impeded by whatever the part is resting upon. Care should be used in making sure it is level so that the kerf will be square, rather than on a slight bevel.

It has been found to be effective to have a member of the inspection department (or some other member of the organization) study the fit-up of parts and to work with the cutting department or the engineering department to describe just what reasons there are for the parts not fitting. Often it is found that if parts consistently fail to fit there is something wrong with a template or with the cutting department's handling of that template. If, however, some one portion of an order of parts is found not to fit and another is found to fit, it will usually be discovered that a mistake is being made in the handling of the template, either in the laying out of the part or in the cutter's manipulation of his equipment. In cases where only a portion of the parts of an order do not fit, the problem can usually be solved by giving further instructions to the cutting department and the cutter involved. However, if all the parts on an order fail to fit in the same respect, then correction of the template through the engineering department and on down to the cutting department often is worth while. To have one man responsible for such check ups is an effective way of checking from the fabrication department back to the source of the workmanship that controls the fit-up.

CHAPTER VII

COST OF POOR FIT-UP AND ITS CONTROL

One of the most important factors in the cost of arc-welded equipment, and one that is most often underestimated, is that of fit-up. There is probably no other single factor that exerts as great an effect on the amount of labor required to produce a

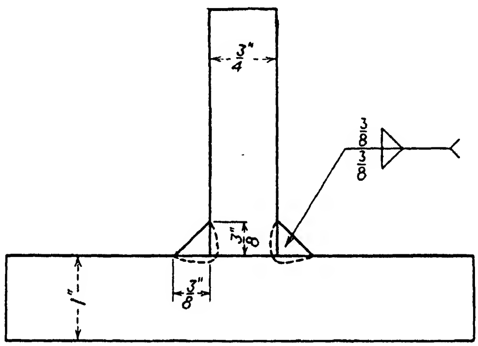


FIG. 89.—A correctly fitting joint with welds of correct dimensional size according to specifications.

given welded structure than the degree of perfection of the fit-up of the parts.

Volume of Weld Metal Required to Fill Gaps.—The relative costs of joints whose component parts fit differently is easily illustrated by a single geometric analysis of the volume of weld metal usually used to weld the joints passably. Figure 89 shows two ⅜-in. fillet welds fusing one plate to another, assuming a good fit-up. (Fillet joints are shown because a large majority of welded joints are of this type. The same principles apply to other types of joints.)

Figure 90 shows the same joint with a gap equal to half the specified size of the weld—not an uncommon degree of bad fit in many joints unless special effort has been expended to improve fit-up.

The total shaded area shown in Fig. 90 indicates the amount of weld metal an average operator will deposit in such a joint. By volume alone, assuming that the joint is welded as shown, the total weld metal used is over three times the amount required if the joint fits properly as shown in Fig. 89.

Few welding engineers would allow much less weld metal to be used in such a case; and since the average operator is not a qualified engineer, and also has an honest desire to be on the safe side in the interest of good workmanship, he will usually deposit more rather than less metal in such a joint as shown in Fig. 90.

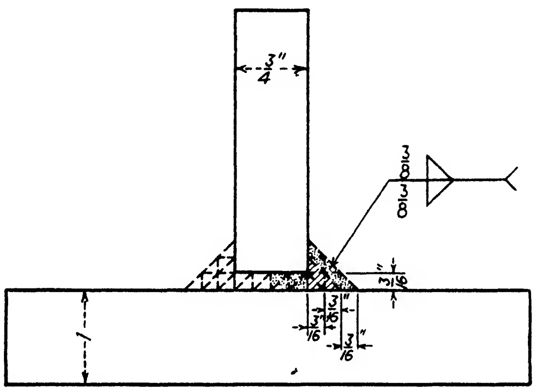


FIG. 90.—The result of a bad fit that leaves a gap equal to one-half the size of the specified weld is that it requires, by ordinary welding practice, over three times the weld metal that is required for a properly fitting joint.

Considering the fact that deposited weld metal seldom costs less than $1 a pound, even in factories whose operations are standardized and repetitive, that the cost per pound deposited for field-welded structures is usually considerably more, and that labor is a large factor in that dollar or more per pound, the cost of depositing two or more times the amount of weld metal per joint than should be required can readily be appreciated. It doubles, or more than doubles, the cost.

Figure 91 shows the same type of joint as that in Fig. 89, except that the gap between the plates is equal to the total size of the specified weld. Such gaps are not so common as a gap equal to half the specified size of the joint, yet an examination of even a relatively simple welded structure composed of several parts, especially if they are irregular in shape, often reveals a

surprising number of inches of joints with gaps equal to the length of the leg of the weld (size of the weld) that is specified to fuse the members of the joint.

A gap of this size is much more of a problem from the operator's standpoint than one half as large. If the joint is welded as shown extending the lower leg ¾ in. along the plate, the joint requires six times the volume of weld metal that it would if it fitted properly. Common practice would seem to be to deposit more nearly five or six times the volume required for a good fitting joint in the case of such a gap than to deposit less, unless the joint is slugged—a practice that is unsound under almost any circumstances.

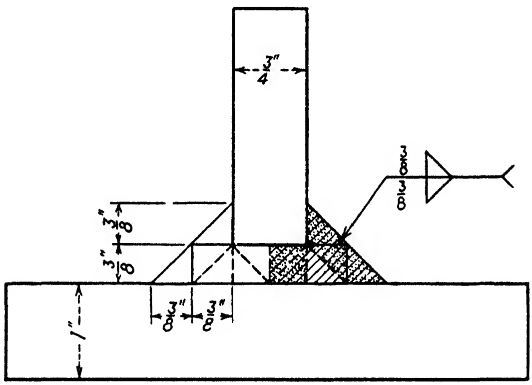


FIG. 91.—The result of a bad fit that leaves a gap equal to the size of the weld specified is that it requires, by ordinary welding practice, about five to six times the weld metal that is required for a properly fitting joint.

Effects of Welded Gaps Other Than Cost.—In addition to the greatly increased volume of metal deposited, other costly factors enter the filling of such a gap.

1. There is sometimes a temptation to put a slug in the gap and try to fuse it to both members of the joint. This is bad practice, because a satisfactory bond can seldom be obtained on all sides of the slug.

2. If the operator fills it with weld metal, as he should, it is always difficult to clean the slag off each pass, and the process is further slowed down by the fact that the members of the joint are not near enough to carry off the heat from a normal weld, to say nothing of the additional metal needed to span the gap first.

3. The additional heat and mass of weld metal often causes an unusual amount of distortion which may cause trouble in the

machining or assembly of the structure or may otherwise detract from the quality of it in use.

4. *The added heat frequently causes excessive grain growth* in the fusion zones of the joint which markedly reduces the strength of the structure, predisposing it to probable fatigue *failure if any undercut is left at the fusion zone and any bending stresses are exerted on the joint.*

The cost, in money, of welding a gap equal to the size of the weld specified to fuse the joint can almost always be considered

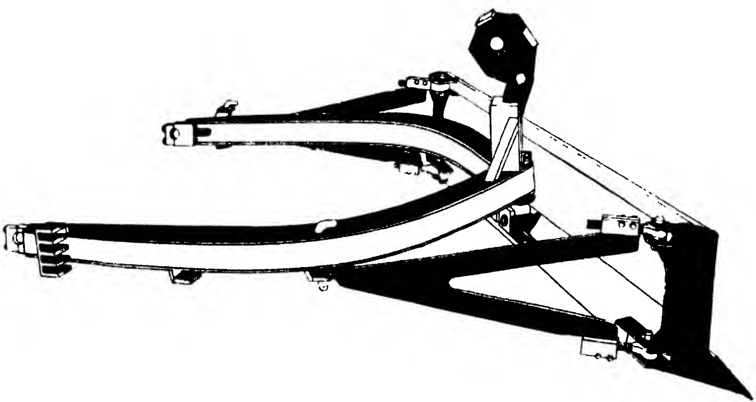


Fig. 92.—Consider the cost of filling gaps on each of the four sides of the long arms of this welded earth-moving unit. Poor fit-up on such structures can be extremely expensive. (*Courtesy of R. G. LeTourneau, Inc.*)

to be not less than six times (and usually much more) the cost of welding the same joint if it fits properly. In addition, the joint produced is almost always inferior to what it would be if it had fitted correctly.

Poor Fit-up and Cost Estimates.—In the interest of accurate estimates of costs of production, a realistic attitude toward degree of good fit-up must be taken by any producer of welded goods. Since many modern machines are being built along curved membered lines, and since the curved lines are almost always flame-cut edges matched to close tolerances with rolled or formed edges of other parts of the unit, the total possibilities of poor fitting joints assumes large economic proportions.

This is illustrated by Fig. 92, which shows a phantom view of a large welded earth-moving unit. The blacked-in portions are flame-cut, and the other curved parts are rolled. Note the

possibilities for gaps along the long curved arms and the possible cost of such poor fit-ups.

Cutting Templates and Fit-up.—It is entirely possible for the manufacturer of machines in lots of 25 or more of the same model to reduce the number of bad fits encountered in the first unit (or even the first pilot order of 5 or 10 units) to almost zero for his larger quantity production. This can be done (1) by making effective use of the first order of each new model to make accurate setup fixtures and accurate cutting, shaping, and forming templates; and (2) by training the workmen who use these templates and set up the parts for welding in the practice of good workmanship.

The correction of templates to conform to the fixtures and parts that were modified or adjusted in building the first experimental unit of a new model machine is of prime importance. If the changes that the experimental department almost always has to make on at least some parts of a new model machine are not accurately and completely carried over as changes on the cutting and forming templates for those parts before the parts for the first "pilot" quantity order of 10 or more are cut, the truly experimental experience on the first machine has been lost, and the price on the pilot quantity order for bad fit-up will probably be high.

When the pilot order has been started through the shop and the first unit or two is being placed on a mass-production basis by the use of setup and welding fixtures, there are usually additional refinements to be made in templates to make all joints in the machine fit properly. These changes should be carefully followed through to completion of new templates at that time, and care should be taken to be sure that the new templates have replaced the old ones when the parts for subsequent production orders of that model are being cut and processed.

The correction of templates is most important because however good may be the workmanship done on material, and however faithful the reproduction of parts from a template, if the template is wrong the parts are wrong and the price is paid for poor fit-up.

Effect of Design on Fit-up.—Some parts in welded machines are more likely to be misfits than others. The parts that are cut to make up the regular, boxlike structure shown in Fig. 93 are much less likely to be misfits than the ones shown in Fig. 94.

In the former, as long as dimensions are held accurately and cuts are square and regular, the parts must fit if they are properly set together. The cutting of a long bevel cut or the development of a bevel cut on a drafting layout on a structural section such as the one in Fig. 94 is much more likely to result in a part that fails to fit, since in the laying out on a drawing board and the development of the original template a slight deviation in

FIG. 93.—The major parts for this machine are square cut, or nearly square cut, and are therefore comparatively easy to cut to fit correctly. (*Courtesy of R. G. LeTourneau, Inc.*)

the angle from that which is actually required may cause a surprising gap. The longer this beveled cut, the greater the likelihood of a gap occurring. Careful following through on the first experimental machine results in the reduction or elimination of serious gaps on such cuts.

The difficulty of cutting and fitting together, without gaps, structures such as those illustrated by Fig. 95 increases with the complexity of the curved sections, yet the most effective use of arc welding with its freedom of design and material distributing advantages causes progressive designers of many kinds of machinery to develop models more along the functional, material-saving design.

The "follow through" to correct templates is even more important in such units because of the greater complexity of layout and greater chance for a small error to be magnified in a large piece of material. The machine shown in Fig. 95 is an example of one that takes advantage of material distribution and effective streamlining to make it function most efficiently.

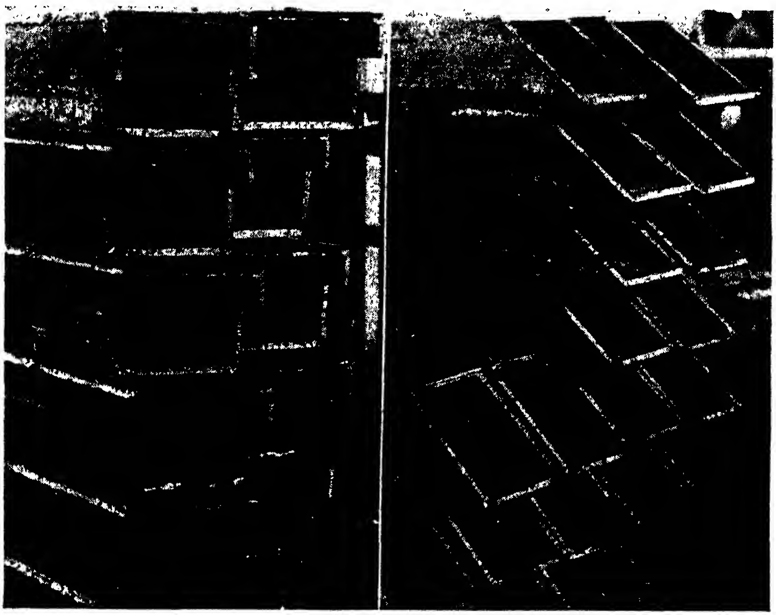


FIG. 94.—Parts with long bevels or offset compound bevels such as these must be faithful reproductions of accurate templates to fit properly. (*Courtesy of R. G. LeTourneau, Inc.*)

Consider the additional cost of welding such a unit if on even half of the curved or angular cuts there were a gap equal to half the size of the specified weld. Yet such a degree of perfect fit-up would probably be very creditable on the first machine built. Some gaps would be wider than the thickness of the plate in all likelihood, unless a much larger amount of engineering time and money had been spent than is necessary from a practical, expedient standpoint.

Effect of Quality of Workmanship on Fit-up.—Training the workmen in the shop to produce good work is primarily an educational problem. If the templates are substantially and

accurately made and the cutting, shaping, and forming equipment are in good mechanical condition, the problem of getting accurately cut and processed parts should not be difficult. The normal desire on the part of the average workman to do a good job makes the practice of inspecting the first of each of the parts cut on an order an effective insurance of good workmanship

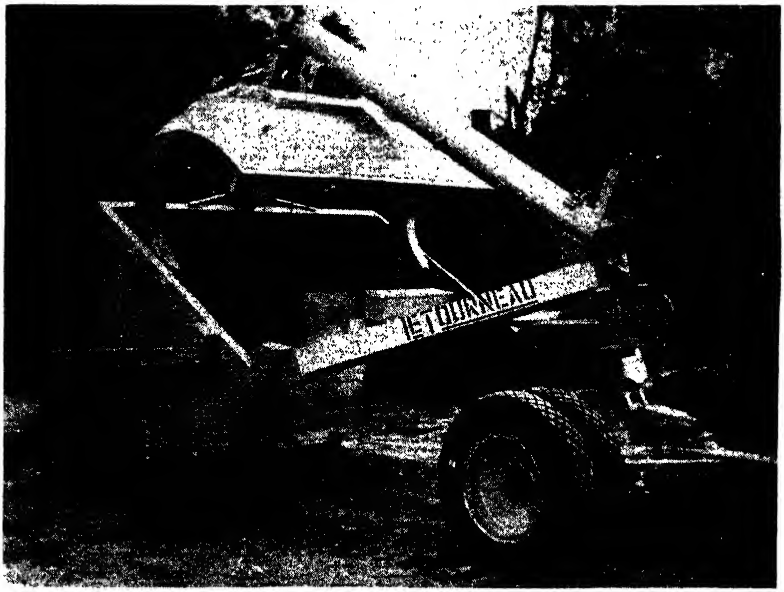


FIG. 95.—The number of curved members, beveled member joints, and irregularly shaped parts in this machine produces a highly efficient machine with a minimum of material; but it also requires careful and complete template development from the first experimental model to avoid badly fitting joints that are costly in subsequent orders on a production basis. (*Courtesy of R. G. LeTourneau, Inc.*)

and accurate processing. If the part is correct, the man has mastered the requirements of workmanship for that particular part, and the rest of the parts can be cut. If it is not correct in all respects, the workman and his supervisor together can analyze the problem of producing it correctly, another part can be cut and checked, and thus a satisfactory degree of perfection for the job can be attained.

Inspection Templates for Press, Bending-brake, or Roll Operators.—Parts such as those which make up the complex gear case shown in Fig. 96 require a consistently high degree of

accurate workmanship, because several of them are irregular in shape in the first place and are then pressed or formed into still more complex parts.

An accumulation of small errors or even one incorrectly done operation can result in gaps that can be extremely expensive,

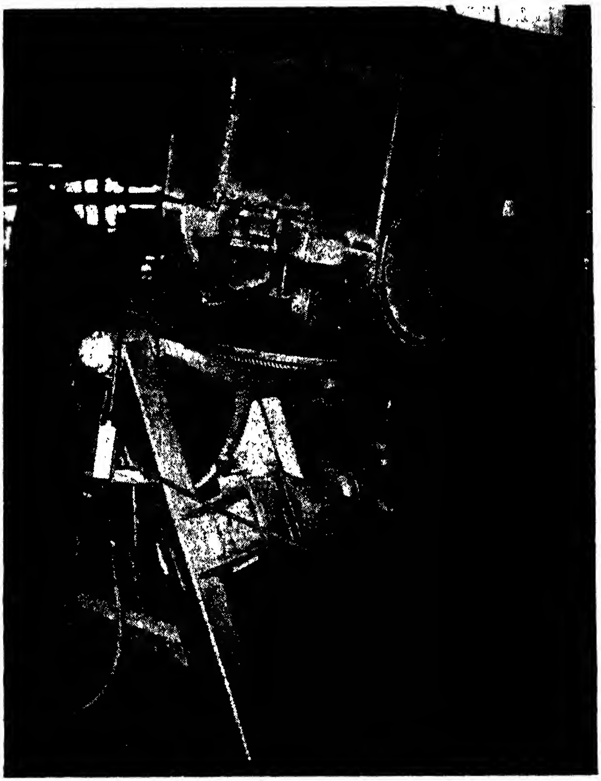


Fig. 96.—Accurate, careful workmanship at every stage of cutting, shaping, and setting up is essential to good fit-up on this 4 ft. deep gear case. (*Courtesy of R. G. LeTourneau, Inc.*)

especially since the welding in this case must be 100 per cent oiltight and the heat introduced into the structure must be held to the least practical minimum to avoid distortion.

Since the parts of many welded structures are formed by pressing or are bent or curved by bending-brake or wringer-roll operators, it is often practical to use checking templates to allow the workman to check his own work as he does it to ensure

accuracy. Figure 97 shows an operator on a wringer roll using a light metal template to check the curve he is rolling into large, heavy parts that will become the side members of box sections.

Similar templates may be easily made and effectively used to allow the operators of bending brakes to check the angle of the bends they make in plates. Also similar devices may be

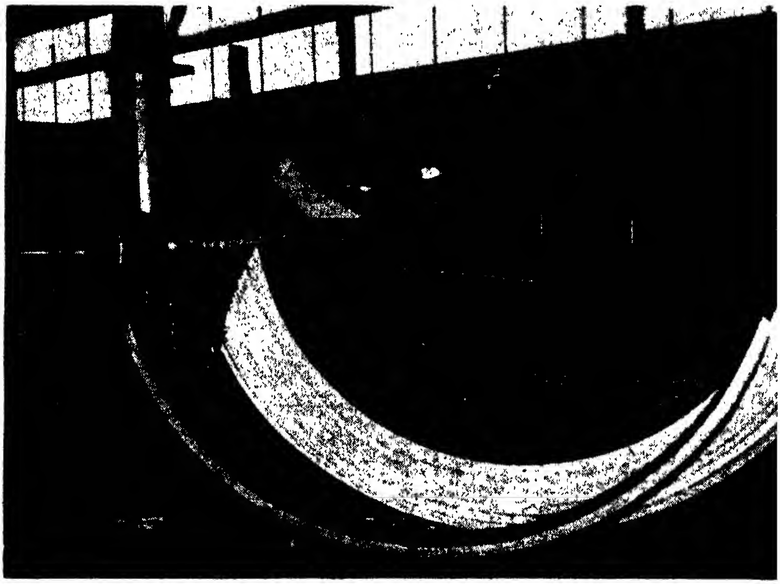


FIG. 97.—By the use of this light-gauge metal template, this operator of a wringer roll can check the curve of the plates he rolls. The check up is quick and easy and gives the man a tool to ensure accuracy of work and, therefore, accuracy of fit-up of parts. (*Courtesy of R. G. LeTourneau, Inc.*)

eveloped for the quick gauging and checking of pressed or formed parts.

Care in Handling Large Parts.—Careful workmanship and correctly made parts cannot ensure good fit-up unless they are delivered to the setup fixture in the accurately formed or processed condition in which they leave the cutting or processing department.

Such parts as the long, heavy, curved parts shown being rolled and checked in Fig. 97 are difficult to handle and easy to bend. If they were to be moved by picking them up with an overhead crane, a slip in attaching the chains could easily allow them to

drop. Such a drop would almost certainly spring some of the rolled curve out of them and would cause hard and expensive hours of work in the setting up process or in the welding of the structures of which they are parts. Many a roll or bending-brake operator has been suspected of poor workmanship when, in reality, the transportation and storage crews are actually the ones guilty of carelessness.

No handling or transportation crew in a welding shop should be neglected when it comes to education on the cost of poor fit-up and on the ease with which parts may be bent in handling.

After the parts for even a simple welding have been cut to fit properly, an accurately built and rigid setup fixture that will allow the setup man to place them quickly, securely, and accurately will lend an additional and profitable degree of insurance against bad fits. The production and use of such fixtures will be discussed in the next chapter.

It is not an exaggeration to state that a large portion of the margin of profit in the arc-welding method of manufacture of machinery may lie in the perfection of the fit-up of the parts. Often the best designs, from the functional and the material-economy standpoints, involve the greatest problem in developing perfectly fitting parts. By intelligent and consistent "following through," by the correction of templates from experimental model to pilot order and thence to first production order, and by exercising careful workmanship, the expense of poorly fitting parts can be reduced to a minor factor.

CHAPTER VIII

JIGS AND FIXTURES FOR ARC-WELDED MASS PRODUCTION

In the routine production of almost any unit or product by the arc-welding method, the use of jigs and fixtures usually pays dividends.

Each individual job requires careful study in the light of certain fundamental considerations before decisions can be made as to the type of jig or fixture that should be made for that job. In this fundamental study, the job should be carefully and thoroughly analyzed from several points of view.

Probably the first and most important is the number of units to be made, since the degree of complexity of the jig or fixture depends entirely upon the total savings that a jig would make possible on a particular job. If there are few structures to be made, the fixture usually must be simpler than if a large number of structures, involving a large amount of work, are to be made.

The form of each unit must be studied to determine whether it can be divided and made up as substructures and structures that can be welded more conveniently, and then assembled as a completed large structure (such as shown in Fig. 98), and as to whether most of the welds on the separate structures are to be found in one plane that might be rotated around a single axis. This largely predisposes the type of fixture that should be made for a structure.

A third consideration is the total amount of welding on each structure. A study should be made in which the number of inches of welding and the different sizes of welds are defined, so that a calculation may be made as to the number of directions in which the fixture should rotate for the positioning of the welds, in order to decide on the type of fixture practical for the part.

A fourth consideration is that of the number of individual parts involved, since this also predisposes the amount of setup time and also, to a considerable degree, the number of welds and their lengths in the structure.

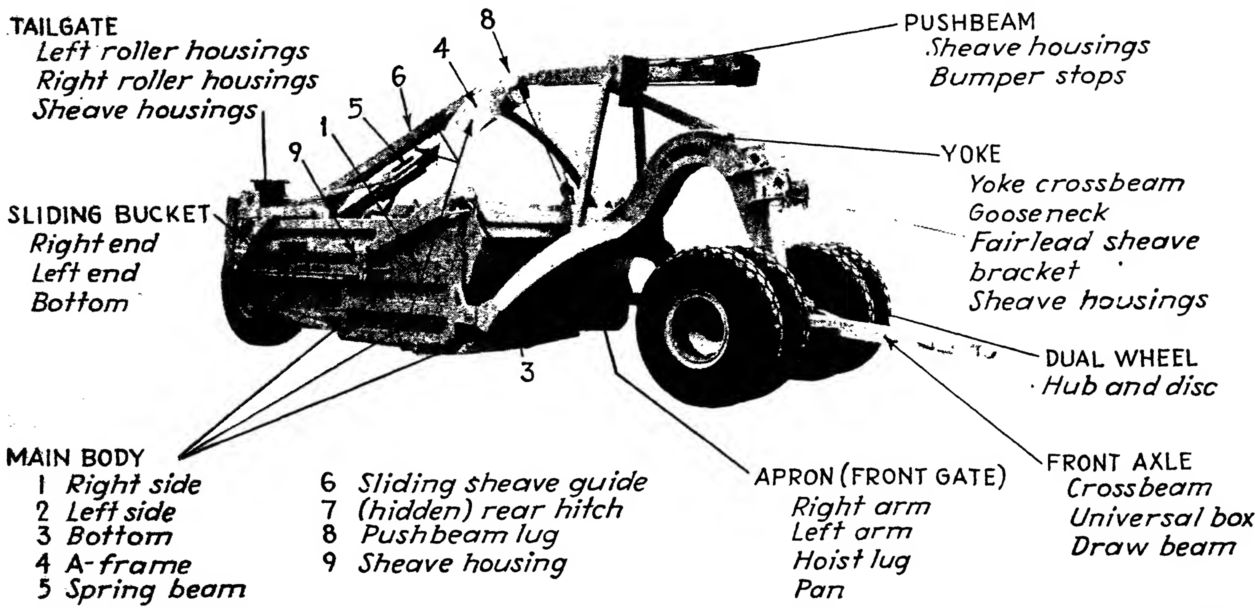


Fig. 98.—This 30 cu. yd. capacity all-welded earth-moving unit is made up of 11 separate major structures. Over 60 substructures are used to make these 11 main structures. Each substructure and structure requires one or more fixtures for its production. (*Courtesy of R. G. LeTourneau, Inc.*)

These studies should be made very completely and, in most cases, should involve the use of a stop watch in order to describe definitely the amount of time that is required for the setting up of the structure and the amount of welding that is to be done upon it. If a large number of parts are involved, a careful study should be made of the amount of time required to set the parts together prior to welding (estimated on the basis of time studies if possible), and considerable thought should be given to the type of fixtures that might be used for setting up or for positioning the welds of the structure.

In the designing of fixtures, there are two separate processes that are effected and, if the proper fixture is made, usually facilitated by the use of fixtures for the job. These are (1) the setting-up process (the placing of the component parts of the structure in their proper relationship and tack welding them together so they will maintain those relationships during the welding process) and (2) the arc welding of the structure into a solidly fused and completed unit.

Bearing in mind these two functions that fixtures may serve, jigs and fixtures that are used in mass production of arc-welded structures may then be classified as follows:

1. Setting-up fixtures.
2. Weld-positioning fixtures.
3. Combination setup and welding positioners.

Considering the fact that a fixture must be built individually for the specific job, there are certain other requirements that should be considered fundamental.

First among these is that it should be as simple as possible to do the job properly. This simplicity should involve the least material necessary for the job, the least possible labor, and the fewest special accessories, simply because a welding jig or fixture is an accessory to the final objective of the production of salable goods. Figure 99 shows a fundamentally simple setup and welding fixture for a structure. Jigs and fixtures are a part of the capital investment that should be kept as small as possible and should be planned along simple lines, so that in the event a change or discontinuation of model is necessary there will be less expenditure involved in jigs and fixtures.

One of the most important phases of arc-welded construction is the ease with which models may be changed or redesigned for

more profitable construction; and the simpler and less expensive the jigs or fixtures, the greater the profit involved in changing models.

Setup Jigs and Fixtures.—Jigs and fixtures used for the setting together of parts of a structure have as their main objectives the reduction of labor and measuring for the positioning of individual parts and the means for holding parts in their proper

FIG. 99.—The large angle iron used here for a setup fixture for the spring-pipe structure is a simple and effective means of setting up these pieces of pipe into a structure. The two simple sets of rollers (in the foreground) are a commonly used device for the simple and inexpensive positioning of welds on tubular structures. (*Courtesy of R. G. LeTourneau, Inc.*)

relationship while they are tack-weided or otherwise fastened together to form a structure that is ready to be welded.

Bearing in mind these fundamental objectives of a setup fixture, a careful study should be made of the unit to be set up, together with each of its parts, so that the setup fixture may form a framework with stops and holding devices that accomplish the following steps most simply:

1. It should be possible to position all the parts positively, and without measuring, in their proper relationship.

2. The parts should be clamped or fastened, with least labor and gadgets, in position to allow for the tack welding of the parts.

3. There should be obstruction-free access to the points that should be tacked in order to hold the parts rigidly and positively together during the welding process. Freedom from obstruction while hammering the tacks is an important part of this setup process because, frequently, if parts may be hammered as they are tacked, they will have a better fit-up.

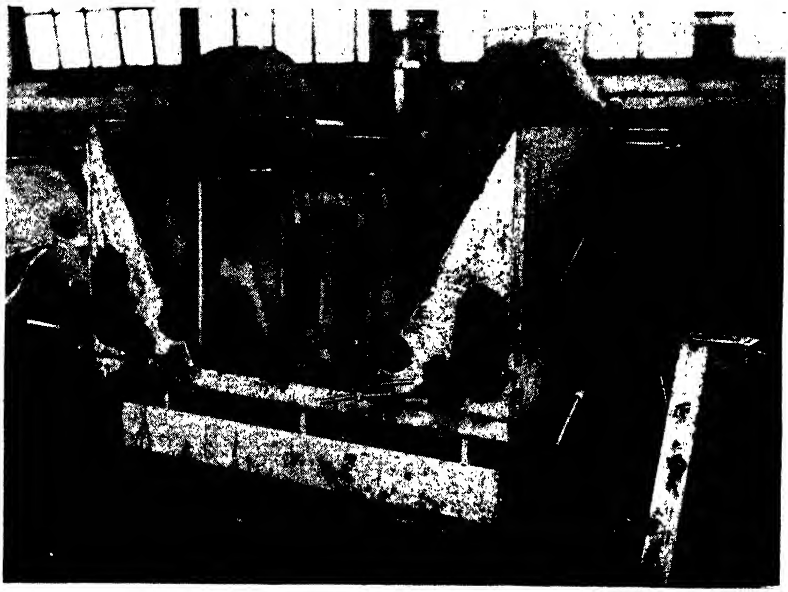


FIG. 100.—Quick, positive, accurate setting together of these closely cut complex parts of a large gear case is greatly facilitated by this accurately machined and carefully planned setup fixture. Close tolerances and clearances required of such welded structures can hardly be obtained on a production basis without such a fixture. (*Courtesy of R. G. LeTourneau, Inc.*)

4. The fixture should have special plugs or stops for premachined or complex parts that positively locate certain holes or other machined surfaces with relationship to other parts. Figure 100 shows an example of such a fixture where a series of machined plugs and clamps and stops are used to fit into closely cut parts of a large gear case so that the parts are held positively in the proper position during the tack-welding of the structure. Accurate and positive positioning of such parts is an essential function of most setup fixtures because either certain surfaces or the premachining on parts almost always marks some

fixed functional part of a machine with reference to some other part and therefore must fit into some final assembly accurately.

5. The setup jig must be made so that the part which has been set up and tack-welded in it is easily removed. The labor of removing parts from fixtures is an important part of the cost of a structure; and unless the parts are easily removed, a portion of the savings that should be made by a setup jig or fixture may be lost.

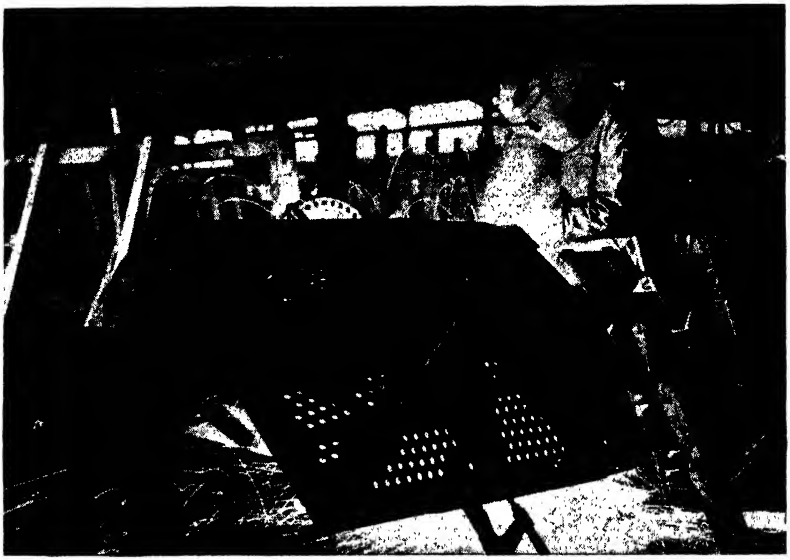


FIG. 101.—The simple C clamps and short cap screws used to hold the parts of this structure in the fixture for setting up and welding ensure the use of only a small amount of time and effort in removing the completed structure from the fixture. (*Courtesy of R. G. LeTourneau, Inc.*)

Figure 101 shows a fixture that employs two simple clamps and a few short cap screws (to hold premachined parts) that when released allow the finished structure to come out easily.

Combinations of tapered plugs, wedges, and clamps, which may easily be knocked out and leave considerable freedom for the removal of parts, may be used even on complex structures in the fabrication of large heavy machines.

Even such a complex structure as the main body structure of the large earth-moving scraper shown in Fig. 102 may be placed in a large, rigid setup fixture. In such an arrangement the proper use of tapered pins, wedges, and clamps will, when loosened, remove the obstructions so that the unit may easily be removed from the

jig. The tapered pins and wedges tend to make removal easier after the unit has been welded and therefore often wedged more tightly in the fixture owing to the "pull" of weld distortion.

One important feature of setup fixtures for structures with premachined parts (and the welding fixture in which the structures are subsequently welded) is that guards or shields be provided to protect the surfaces of the premachined parts from

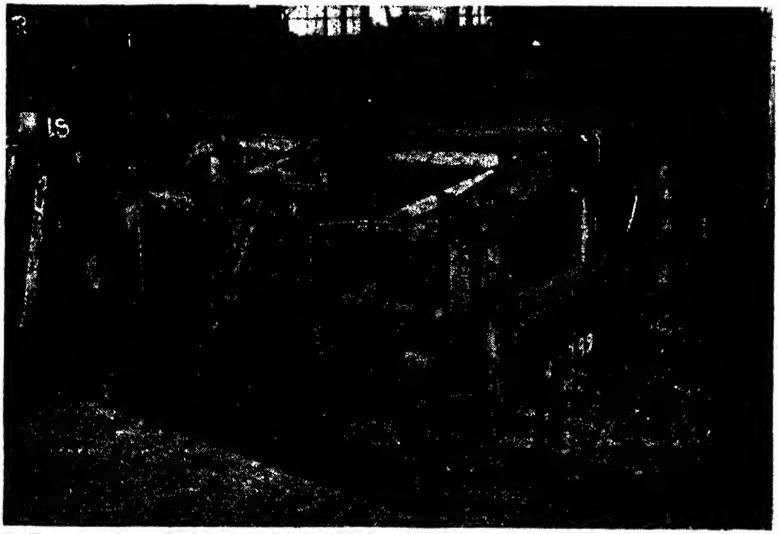


FIG. 102.—Careful study in the placing of clamps, tapered plugs, and wedges make it possible to remove this large and complex structure (an earth-moving scraper main body) from the fixture after the setting-up and welding processes are complete. (*Courtesy of R. G. LeTourneau, Inc.*)

weld spatter drops during the tack-welding for setup, and later for the same protection during welding. Such protection is not always difficult to provide, as is shown in Fig. 103, where a completely machined and heat-treated pinion gear is being welded to a drive plate.

The finished structure (shown to the right) is the setup fixture that is used to position the pinion gear to the plate. Note that the pinion fits into a closed, cylindrical container with an end clamp which may be used to adjust the pinion upward. The drive plate is placed flat on the top of the setup table and adjusted by a bored hole in the drive plate that fits over the end of the pinion, thus completely covering the pinion and pre-

venting the spatter drops from marring its surface during tack-welding. A simple tubular shield with a closed end is slipped over the pinion during the final welding operation to protect its surface. Such protection must be given premachined parts to ensure their proper function when the machine is assembled and in operation.

FIG. 103.—Premachined parts such as this completely machined and heat-treated pinion gear must be protected from weld spatter drops during tack welding as it is being set up and also during welding. Note the setup fixture that encloses the gear during the setting-up process (immediately under the finished structure in the picture) and the tubular guard used during welding. (*Courtesy of R. G. LeTourneau, Inc.*)

Weld Positioners.—The primary function of a weld-positioning fixture is that of holding a structure and making possible the turning of it so that the welds may be placed in the most favorable position within the realm of the best economy of the welding process.

Fixtures for positioning of welds, like those for setting up of parts, should usually be made specifically for the job for which they are to be used. Generalization of fixtures for some types

of parts is possible, but in almost all cases positioning jigs should be made specifically for structures they will position.

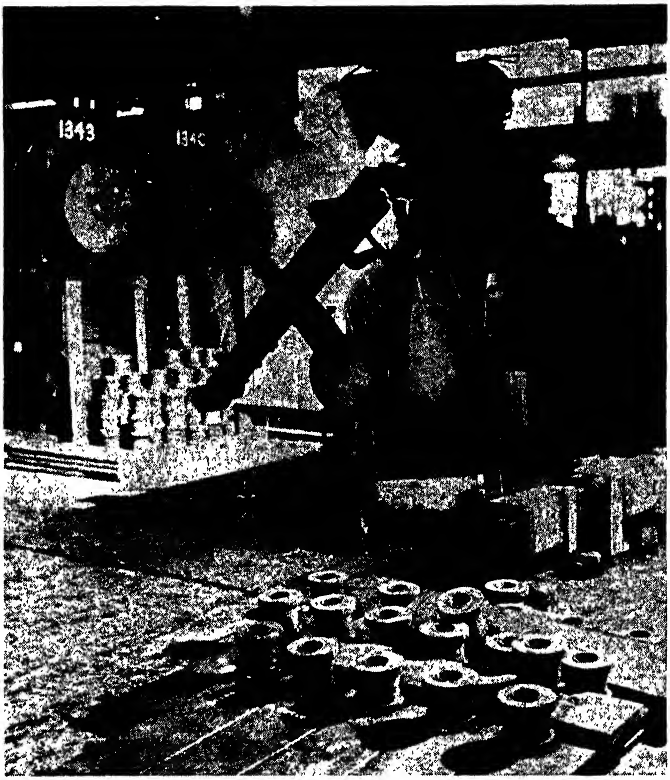


FIG. 104.—The welding fixture used for welding these structures is a simple, yet effective, positioner. Note the simple hold-in clamp, the adjustable angle axle, and the unobstructed clearance for turning of parts during welding. (*Courtesy of R. G. LeTourneau, Inc.*)

Welding positioners may be grouped for the purposes of discussion in four general groups as follows:

1. *Fixtures for Small Parts and Structures.*—Parts that may be handled relatively easily, and may be turned by hand as the operator is depositing his weld, may frequently be placed on welding-positioning fixtures such as the one shown in Fig. 104, which involves a single point of suspension on one plane (the axle adjusted to 45 deg. from perpendicular for this structure) that allows the part to be placed on the axle and turned by hand

and to position at least certain welds on the part in the strictly down-hand position.

Note that a square, boxlike structure which has four welds on each end could be placed on the axle, and each of the four welds on each end could be welded in the strictly down-hand position by turning it on the axle 360 deg.; then by removing the part and turning it so that the other end is up, the welding process can be finished in the completely down-hand position.

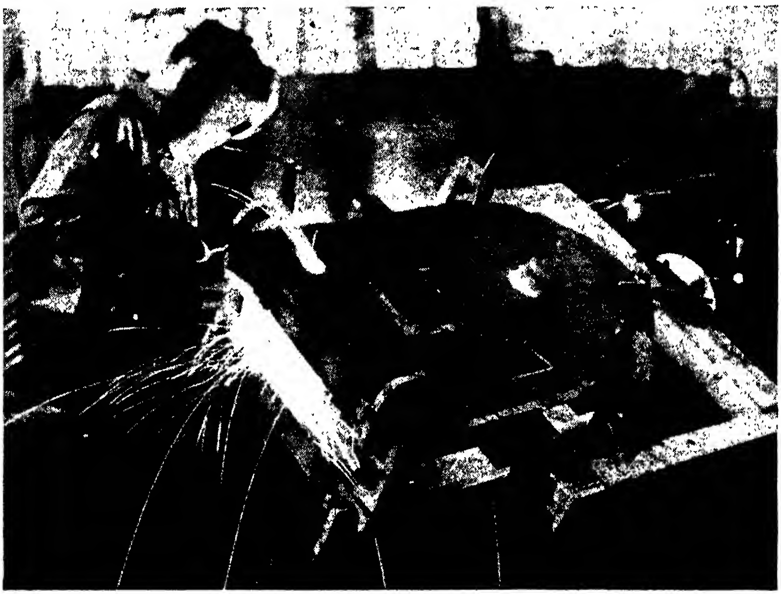


FIG. 105.—This fixture is an adaptation of the one shown in Fig. 104, so that parts may be rotated into any position required for strictly down-hand welding. Note the simple hold-down clamps and locating stops on the fixture which is suspended on a secondary axle crosswise to the direction of the primary axle. (*Courtesy of R. G. LeTourneau, Inc.*)

This type of fixture is one of the simplest and lends itself to a large variety of parts if it is properly constructed. It serves well for circular parts that may be turned as the welding operator deposits his metal without any additional power drives.

The variation of the fixture in Fig. 104, which is shown in Fig. 105, allows for the positioning of a part in any position desired, simply because it has a secondary point of suspension, the combination of which with the first one makes a universal positioning unit. This type of fixture is effective for small parts that are

irregular in shape or have a large number of welds in different planes and that would be difficult to position otherwise.

2. *Spinner Jigs for Medium-sized or Large Structures.*—Many structures upon which the majority of the welds lie around one central plane may be welded in a simple fixture consisting of a central axle upon which the structure is mounted, suspended by two end frames, such as are shown in Fig. 106.

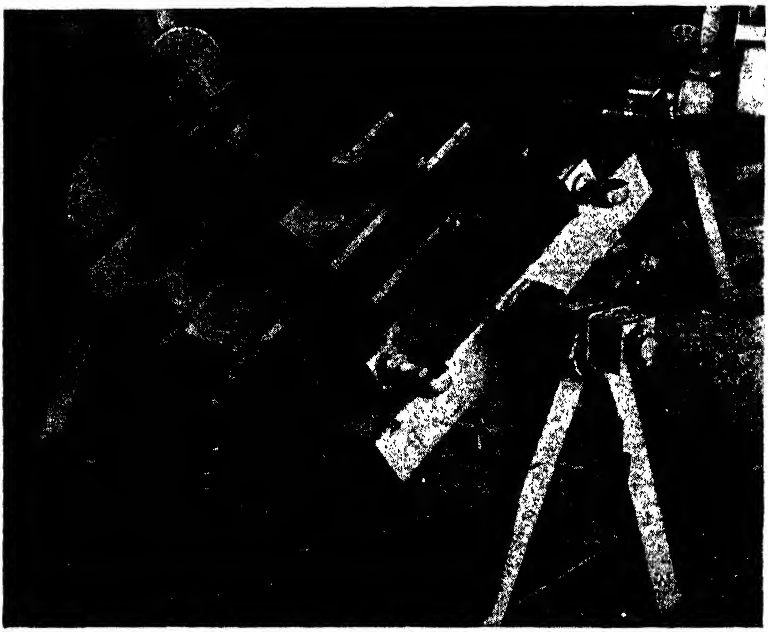


Fig. 106.—Since all but a few short welds lie around one central plane in these structures, the fixture consisting of a central axle suspended on end frames provides a practical means of positioning most of the welds. (*Courtesy of R. G. LeTourneau, Inc.*)

If careful study of a structure shows that there is a sufficient quantity of welding in one direction, or centered around one plane, so that to spin it in only one direction will position a large enough percentage of the welding (not necessarily number of welds or inches of welding), then the simplicity of a two-point suspension fixture around one axle will best solve the problem of positioning the structure for welding. There may be some welds that will not be positioned, but they can be welded in the horizontal fillet position in most cases and may, thus, be less expensive

than it would be to position the entire structure for complete down-hand welding.

This type of fixture is often found to be most economical for even some large and complex structures. An example of such a structure is the scraper body in the spinning jig, shown in Fig. 107.

FIG. 107.—Even large, complex structures such as this 8 cu. yd. capacity earth-moving scraper body may be suspended for most favorable welding in a "spinner" type positioner, which gives considerable economic advantage over depositing the welds without positioning. (*Courtesy of R. G. LeTourneau, Inc.*)

The parts that constitute this unit are set up in fixture, which is shown in Fig. 102. After the parts are positioned and tack-welded, the whole setup fixture is picked up by an overhead crane and placed in the socketlike hubs of the spinning fixture so that the whole unit becomes a spinner for the scraper body and its setup jig. This particular unit is designed so that all but two

long welds may be made in this fixture before the part is removed from the setup fixture and the spinner.

Here again, in the application of this type of fixture to large structures, a careful study must be made of the expense of positioning the entire unit for down-hand welding compared with the

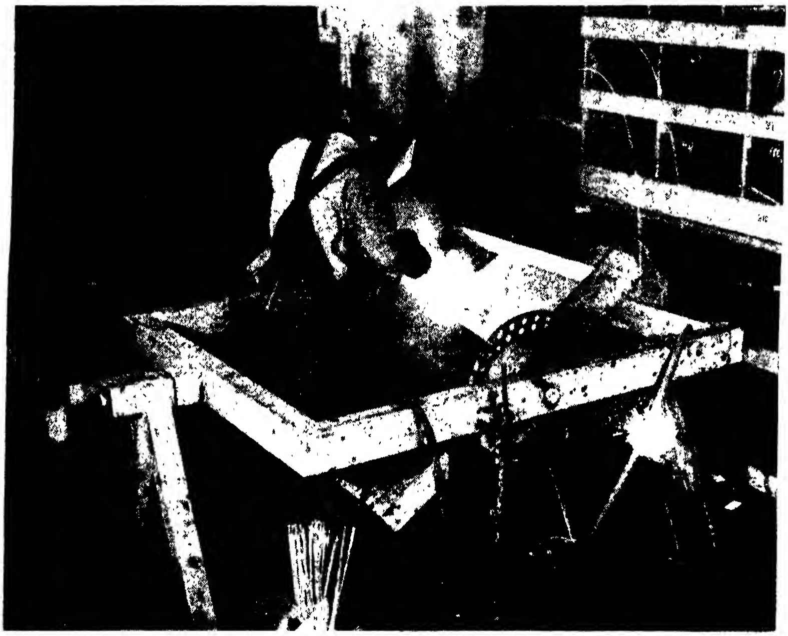


Fig. 108.—This spinner jig which has a secondary axle to provide universal positioning of relatively large structures offers a margin of economy on some types of structures. Careful time studies or estimates of welds on a structure will indicate whether or not the more complex fixture will be more profitable for that structure than the simple spinner. (*Courtesy of R. G. LeTourneau, Inc.*)

extra cost of the fixture and the handling required to do such positioning. Often it is found that to spin around one plane is all that is economical, considering the ease and speed with which horizontal fillet welds may be made with modern shielded-arc electrodes.

3. *Spinner Jigs for Universal Positioning of Large Structures.*—Some large and boxlike or oblong structures such as motor bases and machine bodies may be profitably positioned in a fixture such as the one shown in Fig. 108.

This fixture is similar to a two-point suspension spinner jig, except that it has within the main axle another framelike struc-

ture that suspends an axle running crosswise with the plane of the first axle and permits a part to be rotated 360 deg. in the plane that runs crosswise (at 90 deg.) to the original plane of suspension.

There are several advantages to this type of fixture, and some disadvantages.

One advantage of this type of fixture is that it allows the complete turning in any desired direction of a structure without removing it from the fixture during the welding process. Another is that it is an inexpensive unit that may be turned by hand by the welding operator and may be positioned so that all the welds around one plane may be made in one rotation of an axle; and then by turning the main axle a part of a turn, all welds around a different plane may be deposited. This type of fixture is readily adaptable to box sections and to many other complete structures that have regularly spaced welds running in one plane, but is not so well adapted to structures with circular welds with varying radii.

One of the disadvantages is that the fixture itself tends to be large because the spinner frame that suspends the axle upon which the structure is placed must be capable of rotating the whole part and must also be suspended on the primary axles. This often causes the structure to be suspended high off the floor or to have impaired clearance for some welds because of the frame suspending the secondary axle.

4. *Power-driven Positioners.*—Power-driven weld-positioning units offer measurable advantages in the welding of certain types of structures, but a considerable amount of caution should be exercised in the acceptance of such units for the majority of the welding in many plants.

The use of a power-driven universal positioning fixture such as that shown in Fig. 109 must be justified on the basis of a careful study of the number of structures to be produced and of the particular type of structure that is being made.

Structures that have the long, heavy welds and varying radii, such as are shown in Fig. 109, may often best be welded in a universal positioning fixture, when there are enough of them to justify the expense of such a fixture.

It must be borne in mind that box sections, such as the one shown in Fig. 109, must be removed from the fixture after half the welds are made, turned over, and finished after being returned

to the fixture. This extra handling is a costly process, and on many small box sections, especially those with straight sides, it is sufficient to justify the use of a spinner jig, which can be made for a small fraction of the cost of a universal power-driven positioning unit.

Gear cases and similar structures involving curved welds or a large amount of welding on a relatively complex and heavy

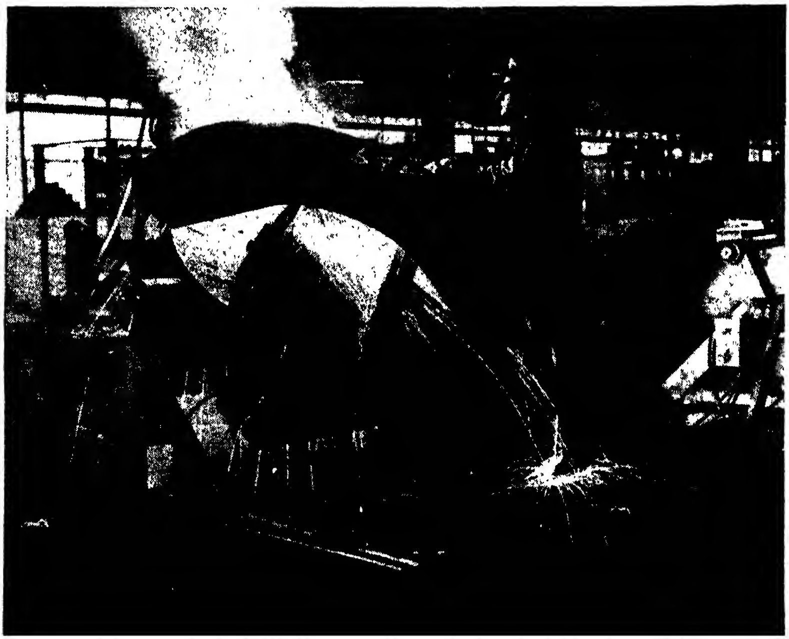


Fig. 109.—Curved box sections and similar structures with long and heavy welds may justify the use of a power-driven universal positioner with variable speed controls, when such structures are produced in sufficient number. (*Courtesy of R. G. LeTourneau, Inc.*)

structure, such as the tractor transmission case shown in Fig. 110, may be welded with greater economy on a universal powered positioner than when other means of positioning are used.

In considering the use of a universal power-driven positioning fixture, it must be constantly borne in mind that such a fixture involves considerably more mechanism than a nonpowered well-balanced spinner fixture. It involves at least one, and almost always two, electric motors, plus the gearing required to rotate the bedplate or main bolt base upon which the parts are

fastened for welding. There are several bearings, and because of the considerably greater complexity of the machine (and usually over-all greater weight), these units are many times more expensive than a simple spinner jig which often will do the same

FIG. 110.—The relatively large number of heavy welds, some of which are curved, on this tractor transmission case makes the power-driven universal positioner practical when the cases are provided in sufficient number. (The substructures in the foreground show the contour of the welds on the inside of the bottom of the case. (*Courtesy of R. G. LeTourneau, Inc.*)

work. The motors, gears, bearings, and controls usually require much more servicing and maintenance than a simple spinner jig.

These power-driven positioning fixtures do have a definite place in the manufacture of certain types of welded equipment where they offer a real economic advantage. However, in all cases where one is proposed for a job, a careful analysis should be made

of that particular job, with due recognition for the first cost of the power-driven positioner and proper consideration for the maintenance of such a unit.

Shop Production of Setup and Weld-positioning Fixtures.—Because almost every positioning or setup fixture must be made for a specific job, there is a great advantage in planning to make it in the shop at the time the first few experimental units of the machine are being made. There are many reasons why it should be made at that time and by the shop crew. Some of the reasons are as follows:

In the first place, probably the best way to make either a setup fixture or a weld-positioning fixture is to make one of the structures without the use of fixtures and then, using it as a pattern, build a jig around it, placing stops for locating certain points on certain parts in the proper place and locating the clamping devices around the original part as the jig is being made. This assures the stops and clamping units being located in the proper places and in the proper relationship one with another. This can be done by workmen in the developmental department as well as by anyone else, if not better.

Another good reason for making these jigs and fixtures in the plant where the problem arises is that if the simple spinner type jigs are used they can generally be made from material that is at hand, and that may even be considered scrap, rather than from new and specialized material purchased for such units.

For a number of fixtures, such as the ones shown in Figs. 106 to 108, there are several generalized parts that may be made up and used on almost any fixture. A group of such parts is illustrated by Fig. 111, which shows axle blocks (made of a short piece of box section, with two bearing end plates welded to it), a turning and stop plate, the parts for a latch assembly, a generalized type of C clamp together with its parts and a holding plug assembly and tubular part, and an axle.

Many of the parts that are commonly used on the simple spinner type positioning fixture may be used with little or no extra work on other jigs when redesign or discontinuation of products makes the original fixture obsolete. The alert and resourceful jig-and-fixture department which has a disregard for "fanciness" as compared with effectiveness will not hesitate to reuse usable parts of production jigs and fixtures as long as

they function properly. The resulting fixtures may not be pretty, but effectiveness is the main objective of such units, and the salvage of used parts for fixtures often pays desirable dividends.

Axles for such fixtures need not be complex because they are slow-turning, rugged pieces of equipment. They need only to be turned to the proper sizes to fit into the hubs, or axle blocks,

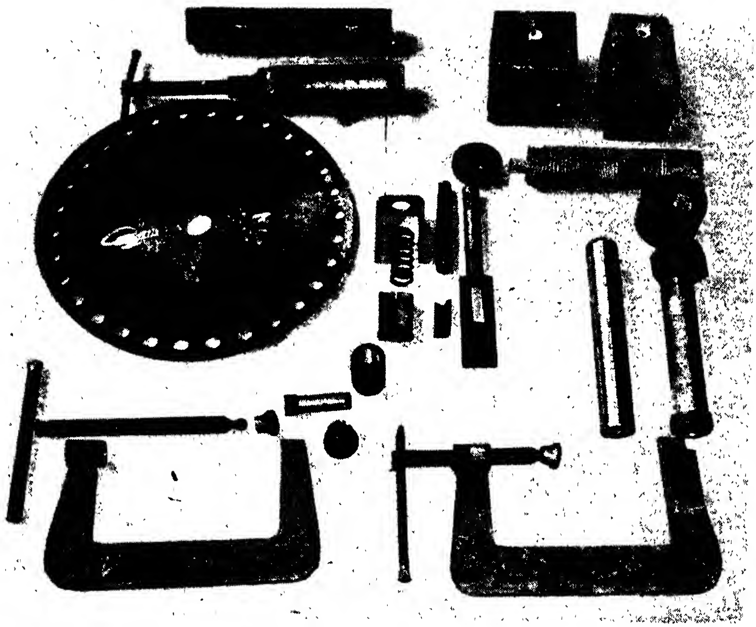


FIG. 111.—This is a group of "stock" items for the jig and fixture department. They will lend themselves to many of the jig-building problems and may often be salvaged from one fixture and used again. Note that the perforated "stop" disk has been cut from one fixture and ground for re-use later. (*Courtesy of R. G. LeTourneau, Inc.*)

and mounted in line so there is no tendency to bind as they are rotated around their axis. Seldom are ball or roller bearings of sufficient advantage to justify their cost.

Almost any structural form or shape could be used for the supporting members for the axle block to raise the jig or fixture off the floor to the proper level. Angles, I beams, pipes, T irons, box sections, or almost any other material that happens to be at hand may be used.

The same general statement may be made about the type of material to be used for the framework of such fixtures. Whatever

material happens to be available to the fixture makers may be used so long as it has structural strength enough and does not involve a considerable waste of material from the standpoint of weight or availability.

FIG. 112.—The two premachined substructures which are "strung" on the positioning bar in this large structure are accurately positioned and spaced by the bar. The inside of the bored pinholes in each structure is protected from weld spatter or other mechanical injury by the tapered bar that holds the structures in place. (*Courtesy of R. G. LeTourneau, Inc.*)

Careful calculation of the center of gravity of both the structure and the fixture should be made by the jig-and-fixture department, or experimental department, as they design and fabricate jigs for parts that must be rotated, because the ease of turning depends mostly upon a well-balanced assembly of fixture and structure. If fixtures are hard to turn, expensive labor and

sometimes costly accidents occur in the turning process. The department that makes the jigs and fixtures should plan not to use counterweights to make the fixtures turn easily. Counterweights in fixtures of this kind simply increase the amount of material that has been put into them, increase the mass of material that must be turned, and therefore reduce the speed at which a workman may turn them.

One of the biggest sources of economy in arc-welded construction is that of being able to use premachined parts. The department that makes jigs and fixtures must be careful to utilize premachined parts whenever possible, so that the total structures, after they have been welded, will not have to be machined.

This creates a need for special stops or shields to position properly and also to protect machined surfaces from injury during the welding process. This may be accomplished by the proper design of the fixture.

Figure 112 shows two premachined substructures being positioned by being threaded on tapered pins that protect the inside of the bore of the substructures and also position the parts positively and accurately in the proper relationship to the rest of the unit.

Welding Distortion and Jig Construction.—Some study on the part of the jig-and-fixture producers in any given plant will teach them certain things about the effects of distortion on the structures that they build; and they may compensate for such distortion by the proper location of their stops, by the total strength of the framework of their fixtures, by studying the means of dissipating the heat from welding by fixture design, and, in some cases, by prestressing the parts so that when they come out of the jigs they are nearly accurate and need little or no further processing to correct the effects of distortion.

An example of such prestressing may be seen in Fig. 113, which shows a large earth-moving scraper side-sheet fixture. The side sheet is welded almost entirely on one side, and therefore the jig itself has been bent to compensate for the distortion that results from such concentrated welding on one side of the structure. These structures are large and made of a thin sheet reinforced by channels so that they do not always come off the welding fixture which has prestressed them as flat as they must be for best operation in the finished unit.

As a means of ironing out the minor irregularities in such large flat structures, such a fixture as is shown in Fig. 114 may be

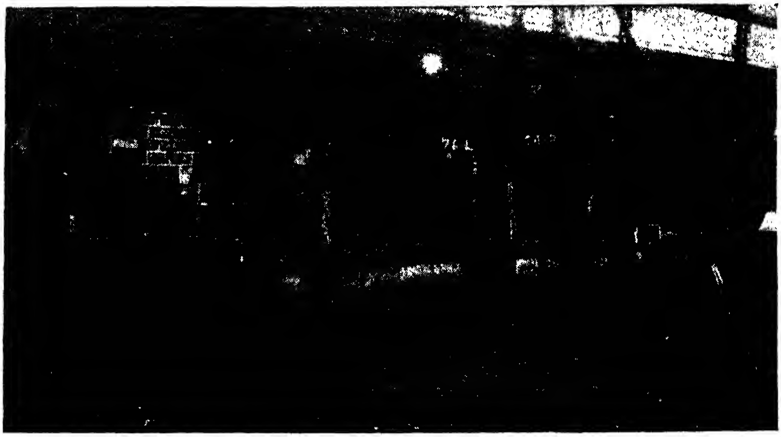


FIG. 113.—The amount of prebending of these parts of a scraper side-sheet structure as they are clamped in the jig has experimentally been determined, so that after welding, when the unit is removed from the fixture, it is almost straight, rather than bowed by welding distortion. (*Courtesy of R. G. LeTourneau, Inc.*)

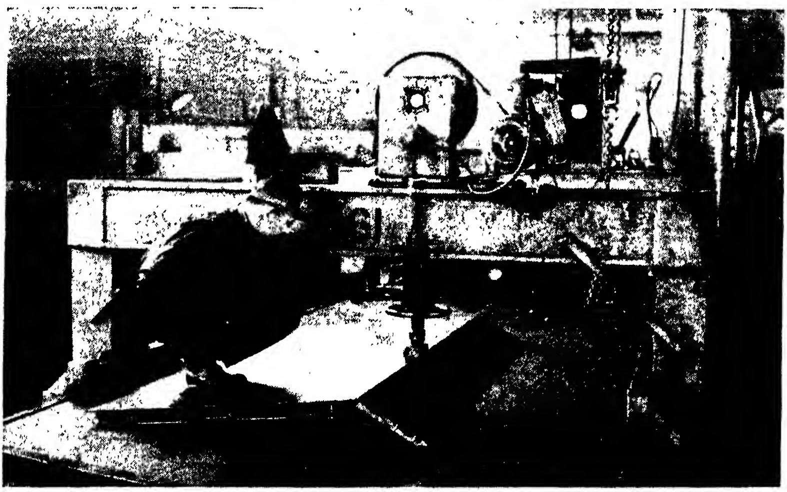


FIG. 114.—This fixture is an accessory to the production of large, flat, welded structures such as the one shown here which requires greater flatness than can be accomplished even by prestressing the structure prior to welding. (*Courtesy of R. G. LeTourneau, Inc.*)

used. It consists of a rigidly built bedplate and faceplate over which the inverted U type frame with a power-driven

hydraulic jack mounted upon it may be positioned. Pressure may be applied to any part of the scraper-bottom structure (shown being "ironed"), side-sheet structure, or any similar large flat structure.

One of the reasons for using relatively heavy structural members in the construction of a welding fixture, aside from rigidness, is to allow for the dissipation of the heat from welding. This is especially true of structures made from heavy plate and upon which there is a large amount of welding. In such cases, it is well to make sure that there are not only heavy parts of the fixture to carry off some of the heat, but also relatively large areas with good close contact from the fixture to the work that will conduct the heat away from the work into the fixture's structural members. Such provision for heat dissipation on the fixtures for structures where it is necessary will usually produce more uniform structures.

Combination Setup and Welding Fixtures.—Often it is good economy to combine the two fundamental functions welding jigs and fixtures offer—that of setting up the structures and that of positioning them for welding.

Many structures lend themselves to being set up in a relatively simple fixture, which can be built so that it is suspended on axles and forms a spinner, and where the setting-up stops and clamping devices give sufficient clearance from the joints so that it is not inconvenient to make the welds. Much may be done by the skillful designer of welding jigs and fixtures to accomplish a satisfactory combination setup and welding fixture.

One of the advantages of such a combination is that it eliminates the extra handling that would otherwise come from taking the tacked structure from the setup jigs or fixture and positioning it in the welding fixture.

Another advantage is that there is no separation of the setting-up and welding functions which, because they are difficult to correlate, frequently either cause valuable floor space to be utilized by structures that are set up and are awaiting welding, or cause expensive time to be lost by waiting on the part of the operator who is setting up the structures and the one who is welding them.

If the man who welds the structures sets them up in a combination setting-up and welding fixture (or in separate units, for

that matter), there is no time lost while he is waiting for someone else to finish a process or finish with a machine.

When the structure is set up by the same man who is to weld it, he is likely to be more mindful of the adjusting of the separate parts so that they fit up more closely (and are therefore much

Fig. 115.—The two arms (hinge-wing structures) of this large scraper apron were built on a separate substructure in a separate fixture and then placed in the main apron setup and weld fixture. The parts of the pan are then set up progressively and welded together so that the entire unit is completed in the main fixture. (*Courtesy of R. G. LeTourneau, Inc.*)

more quickly welded) than he would be if someone else were to weld it.

Still another advantage in having one man both set up and weld the structures is that the man who sets up the parts must have a welding machine available for tack welding the parts. When the same man welds and sets them up, there is only one machine involved and therefore less time when the machine is lying idle and thereby adding expense.

Complex parts or welded substructures may often be placed in a combination setup and weld-positioning fixture such as shown in Fig. 115, and additional parts may be set up to them and welded into a larger, complete, main structure.

In the front-gate (apron) structure being set up and welded in Fig. 115, the side-arm substructures are welded in a separate fixture and then placed in the main setup and welding fixture for the apron. The separate parts that go to make up the main

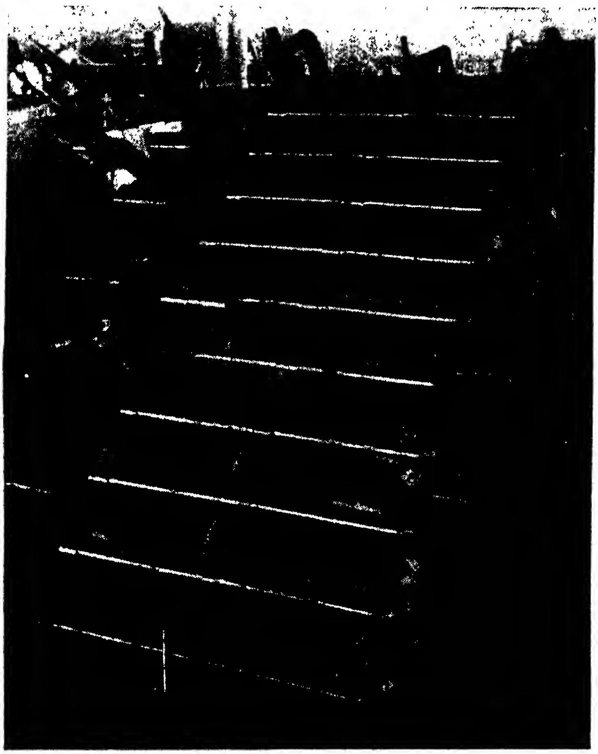


FIG. 116.—There are 29 long welds on this scraper-bottom structure. Since these units are produced in shop order lots of 50 or 100, the installation of a special positioning fixture was justified to change the welding from the horizontal-fillet to the down-hand position. About 2½ hr. per unit were saved by unit (see Fig. 117). (*Courtesy of R. G. LeTourneau, Inc.*)

apron pan or front-gate structure are then placed in the fixture, tacked, and welded—the entire operation being done by one operator or a team of two operators who work together.

Specialized Welding Fixtures.—In a large production shop in which machinery is manufactured by the arc-welding process, there are frequently certain units that justify the manufacture of a specialized and somewhat more complex fixture than a simple spinner type generalized jig.

Such a structure is illustrated in Fig. 116, which shows the bottom structure of a large earth-moving scraper in position on its combination setting-up and weld-positioning fixture.

Figure 117 shows the fixture's mechanism for positioning in each of four directions. The 29 long welds that may be deposited from one side of the structure during its fabrication may then

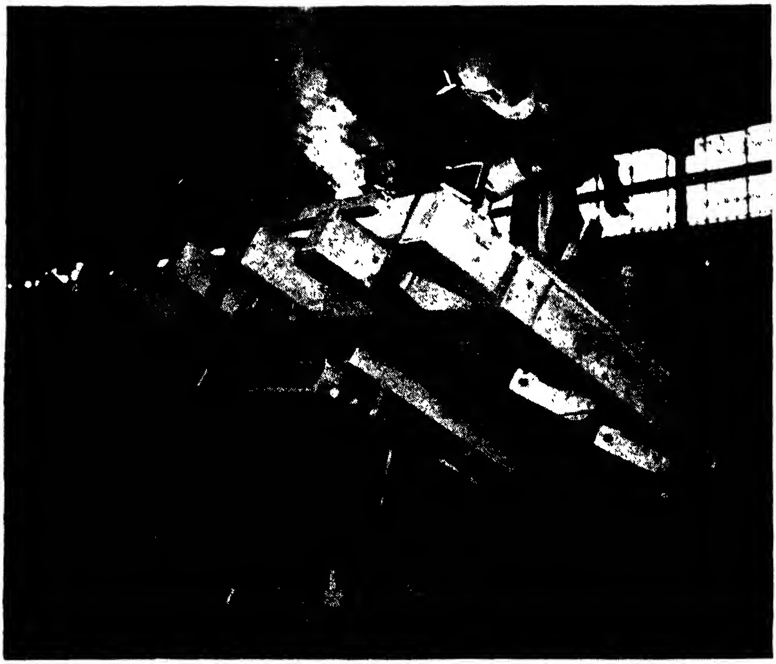


FIG. 117.—This positioning fixture positions the bottom structure shown in Fig. 116 for complete down-hand welding by tilting to a 45-deg. angle from the horizontal plane in each of four directions. (*Courtesy of R. G. LeTourneau, Inc.*)

be deposited in the strictly down-hand position instead of the horizontal fillet at a saving of about 2½ hr. per unit.

Obviously, the considerable advantage in the deposition of these welds, plus the quantity of the welding per structure (these units are made in lots of 100), justified the expenditure of some time and money in manufacturing a specified fixture. It is powered by an air cylinder underneath it and has a series of hooks that hold one side down and release all other sides, thereby causing the structure to be positioned for welding so that all welds in one plane may be welded.

General Advantages of Welding Jigs and Fixtures.—Many definite economic advantages accrue to the organization which builds efficiently operating welding jigs and fixtures.

Although more is said about the advantages of using weld-positioning fixtures than about those of using efficient setup jigs and fixtures, greater benefits are probably derived from the latter type of fixture.

A properly constructed setup fixture may often reduce the amount of labor in handling and in measuring parts in the setting-up process as much as 80 or 90 per cent on an ordinary setting-up process in a routine manufacturing job over the setting up of the same structure without a fixture. This saving in labor alone is considerable, but it is only one of several advantages that come from the use of such equipment.

Another is that a workman who has had less training and who therefore may, in some respects, be less skilled may be successfully given the job of setting up such structures, simply because the fixture makes it possible to get the parts together in their proper relationship without measuring and without error and is, therefore, practically mistakeproof.

Good setup fixtures result in structures whose parts are placed together in proper relationship and, therefore, fit properly, leaving fewer holes for the welding operator to fill up. Often a good weld setting-up fixture will cut the amount of poor fit-up because of misplaced parts sufficiently to reduce the welding of certain joints 50 to 75 per cent.

Structures that are set up in properly designed setting-up fixtures will be found to be uniform and interchangeable—a prerequisite of mass production and yet one that is seldom found when parts are positioned by hand, without the use of jigs and fixtures on a large-scale operation.

The advantages that accrue from the use of weld-positioning units are recognized to amount to as much as 25 to 35 per cent of the welding cost on the average structure, using the materials common today and making ordinary machinery or equipment.

In addition to the reduction of time required for depositing the welds, there is almost always an improvement in their appearance, for those deposited in the strictly down-hand position often have a better appearance than those welded in the horizontal-fillet, vertical, overhead, or horizontal-butt weld position.

A further saving is encountered because of the fact that in almost every case where all welds on a structure may be deposited in a strictly down-hand position a welding operator of fewer years of experience may produce as satisfactory a job as an older, more experienced, or more highly skilled operator. Good welding positioners, therefore, tend to decrease the training problem of welding concerns by shortening the training period for the operator.

Welding-setup and weld-positioning fixtures are not expensive equipment as long as they are kept simple and are made from the materials at hand. They are one of the most profitable investments that a mass-production arc-welding organization may acquire. The acquisition of such fixtures depends mostly on the mode of thinking of the organization and on the training of the experimental department to the economies of the production of such fixtures so as to serve best the requirements of each individual job.

CHAPTER IX

INSPECTION OF MASS-PRODUCTION ARC-WELDED PRODUCTS

One prerequisite of a manufacturing process that can be applied on a broad scale and with a high degree of economic success is ease of quality control of the process. Effective inspection and quality control of the arc-welding process for manufacturing equipment has been shown to be possible by the

FIG. 118.—The quality of much of the modern arc-welding production can be inspected and controlled by visual inspection and procedure control. This all-welded heavy-duty earth "rooter" and the cable-controlling power unit (on the tractor) prove by withstanding the most abusive service that such methods of quality control are practical. (*Courtesy of R. G. LeTourneau, Inc.*)

tremendous quantities of products and great variety of construction which has been done by that process in the past ten to fifteen years. The methods of inspection and control for arc welding vary considerably with the different jobs to which it is applied.

Much of the welding that is done today is inspected by simple, nondestructive, visual methods and a reasonable degree of supervisory control prior to and during the welding process. The heavy-duty earth-ripping rooter shown in Fig. 118 and the

power-control unit that actuates it (a clearer picture of its welded construction is shown in Fig. 119) were both built on a mass-production basis, with controlled processing and visual inspection.

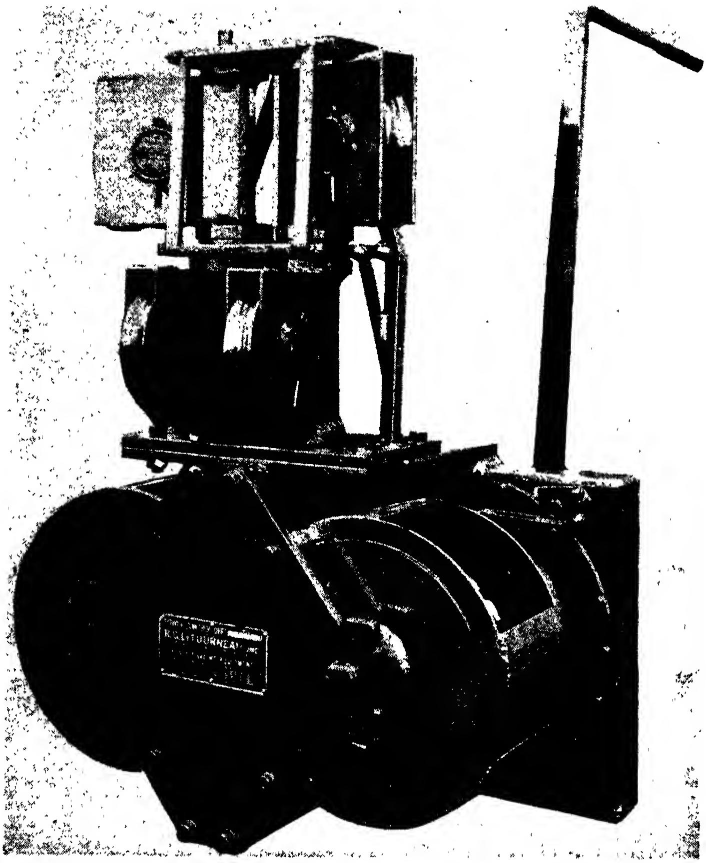


FIG. 119.—A close-up to show the arc-welded construction of the cable-actuating power-control unit shown on the tractor in Fig. 118. All the welds on this unit were specified by complete engineering control and visually inspected to meet the required specifications. Heavy impact and high-tension loads are all in the day's work for these welds. (*Courtesy of R. G. LeTourneau, Inc.*)

Aside from the nondestructive, visual type of inspection, there are other methods that may be used when the design or end use of the equipment requires a more complete analysis of the perfection of the welding job such as the X-ray, gamma ray, electromagnetic flux, or stethoscopic method, all of which require a

certain amount of specialized equipment and specially trained personnel, which naturally increase the cost of the product but are entirely justified in certain types of equipment.

Welded structures that involve a high degree of public liability, such as boilers, pressure vessels, and petroleum-cracking stills, are required by law to pass certain standards of quality of welding as specified by certain codes for their examination.

Other types of equipment, especially military, where the design of the equipment reduces the amount of metal and the weight to the lowest reasonable minimum and therefore requires the highest degree of perfection of welding of the parts that is possible, also frequently justify the use of the nondestructive but expensive and highly technical methods of inspection such as X ray, magnetic flux, or combinations of the two (the magnetic-flux method effectively complements the X-ray method by detecting types of flaws that sometimes would be overlooked by the X ray in castings, weldings, or forgings).

There is an abundance of information obtainable on the use and application of the specialized types of nondestructive welding-inspection equipment and processes. Any organization that would embark upon a type of production requiring such methods of inspection would not only immediately encounter the need for such inspection when they started the work, but would also have contacts with insurance agencies or the purchasers of the equipment through which they could become informed on the subject. For that reason, the discussion of these specialized methods will not be presented here, and the rest of this discussion will be confined to the simpler nondestructive methods of visual examination and quality control that must be used in all kinds of welded construction whether or not other specialized means of inspection follow.

Specifications Must Precede Inspection.—Before any controlled production by the arc-welding method (or any other method) of fabrication can be achieved, there must be certain engineering information made available to those who produce the work and also to those who inspect the work.

This is especially true of the arc-welding process where the inspector, as well as the operator, production foreman, and engineers, must know the answers to certain questions regarding each weld on each structure before they are in a position to

determine whether it passes or fails to pass the proper standards of quality.

This control is sometimes organized by word of mouth and by individual judgment on the part of workmen in every stage of the operation following the completion of the blueprint for the structures in the engineering department. Such a method of control is precarious in even the smallest of welding organizations and is almost certain to involve considerable losses of efficiency and economy in the manufacture of products on a large scale.

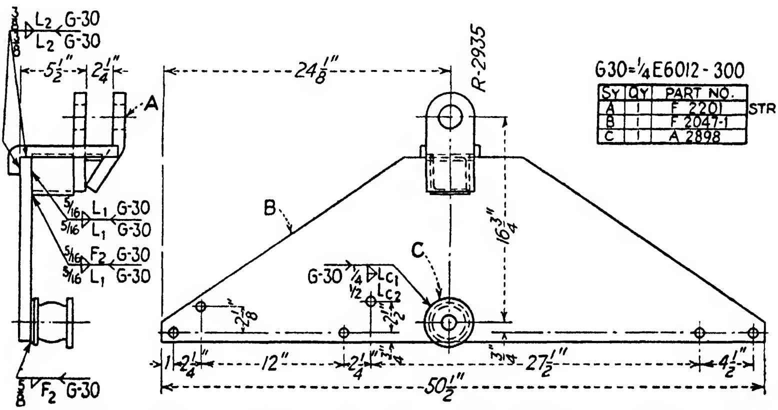


FIG. 120.—Before an inspector can determine the degree of quality he needs, the engineering information such as size, location, form, and type of weld plus the other information that can be made standard for workmen, foremen, and inspectors by weld symbols should be specified on the prints of the welded structure. (*Courtesy of R. G. LeTourneau, Inc.*)

The orderly presentation of the fundamental engineering information required by the welding operator who deposits the metal and the inspector who must pass upon its quality may be presented in several ways, but probably the most effective and simplest is that of the use of welding symbols on the blueprint of the substructures or structures to be welded such as shown in Fig. 120.

Such symbols, the standardized basis for which has been established by the American Welding Society, described in detail in Chap. III, show such fundamental things as the following:

1. The specific joints of the structure that are to be welded and their location.

2. The size of the weld (amount of weld to be deposited).

3. A cross-sectional view of the finished welded joints so that the form of the completed weld is known.

In addition to these fundamental points, it is entirely practical (and economically profitable) on a large-scale welding operation to further show on the weld symbol base the following information:

4. The type of welding electrode to be used for each joint.
5. The machine setting (welding current limits) to be used.
6. The number of separate layers or passes of the weld metal for each joint.
7. The position in which each pass or joint shall be deposited. (If the number of passes is to be shown, then the position in which the weld shall be deposited must be shown.)

To organize such specific information and present it in symbol form on the engineering blueprint from which the workmen, foremen, and inspection department all operate is to standardize and make possible complete control of the arc-welding process. Such a system of control obligates the organization to the construction of fixtures and the standardization of the fit-up of the joints of structures so that the operator may meet these specifications, but that is a part of the organization of any method of manufacture and may be accomplished with the arc-welding process just as well as with other common means of manufacturing.

Strength of Weld Metal Compared with Parent Metal.—Since the weld metal that is deposited to fuse the various parts of a structure becomes an integral part of the unit, it is helpful for welding inspectors to bear in mind certain relationships between the strength of the weld metal and the strength of the parent metal, and also the fundamental principles regarding their function in the welded joint.

In order to prevent the curse of overwelding, which is the common tendency arising from a desire on the part of all workmen to do a job that will be a little better than necessary rather than one that may fail, an examination of certain types of welded joints should be made in order properly to evaluate the need for the correct amount of weld metal—no more, no less.

Figure 121 shows several types of joint preparation for welds that automatically limit the quantity of weld metal to the thickness of the plate plus a reasonable amount of crown. Normally, the amount of crown deposited upon such welds should be main-

tained at the lowest amount practical, which is the least amount possible without resulting in undercutting at the junction of the parent metal and weld metal. It has been demonstrated, by means of polarized-light examination of plastics or celluloid reproductions of such joints, that any additional crown (see *C*, Fig. 121) on such a weld tends to concentrate stresses through

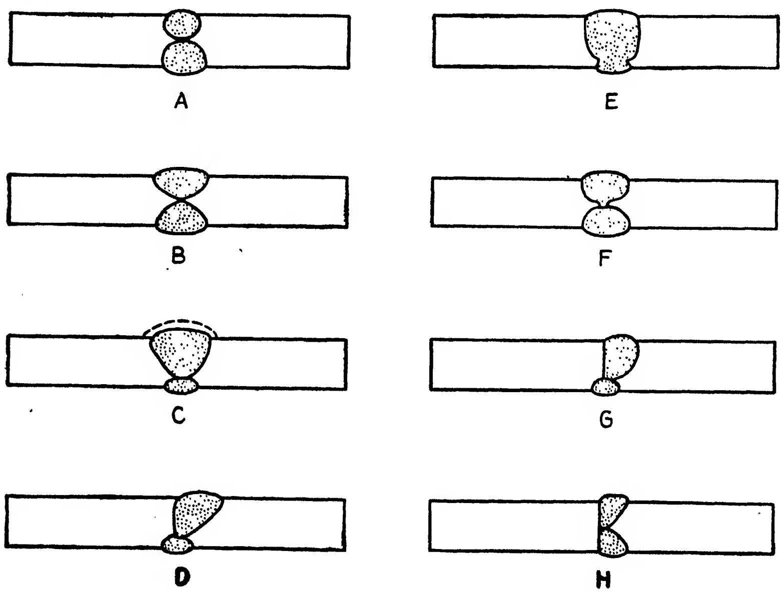


FIG. 121.—These butt joints, though they vary as to joint preparation (use of straight bevels in *B*, *C*, *D*, and *H*, and *U* or *J* bevels in *E*, *F*, and *G*), depend on welded joints no larger than the plate thickness. Excess metal as shown in *C* is waste and weakens the joint. Successful butt joints prove that the strength of weld metal is usually greater than parent metal in ordinarily weldable steels.

the joint in a manner that leads to failure of the weld at a probability rate that increases rapidly with the amount of excess metal above the surface of the joint.

Common fillet type joints that occur in T joints comprise a large percentage of the separate welds in some types of equipment, and because the length of the legs of the joint may be increased to much more than the thickness of the metal, it is extremely important that the size of such joints be carefully controlled.

Figure 122 shows a series of fillet type joints in which the amount of metal to be deposited depends upon the welding

operator and not the thickness of the plate. It also shows the importance of maintaining proper size relationship, since the increase of weld dimensions on that type of joint increases the volume of weld metal deposited and, therefore, the cost of the

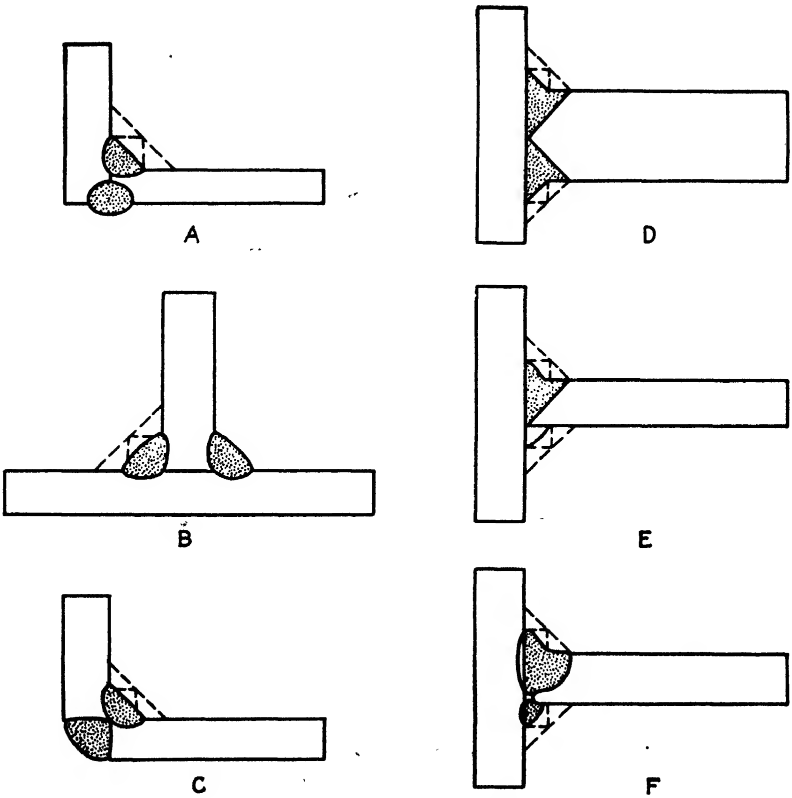


FIG. 122.—These fillet type joints may easily be overwelded to the extent shown by the dotted lines. Such overwelding should be discouraged by inspectors as much as underwelding, since it is expensive and often weakens the joint by grain growth and stress concentration.

welding process by the cube, not the direct ratio, of lineal dimensions. Note the volume of weld metal in the dotted-in sections representing common degrees of overwelded joints.

The deposition of excess metal in such joints is not only wasteful because it is more expensive, but is also accompanied by stress concentration, because of greater amounts of weld metal and therefore greater amounts of contraction upon cooling. It is

also accompanied by grain growth in the metal adjacent to the weld which seriously weakens its structure and increases the possibility of failure. If a welded joint involves twice the lineal dimensioned size it should have if it were properly welded, it will almost certainly not be twice as strong, even though it includes four times as much weld metal.

The considerable number of butt type joints that are made with the weld metal only slightly in excess of the thickness of the plate demonstrates that the relative strength of weld metal is

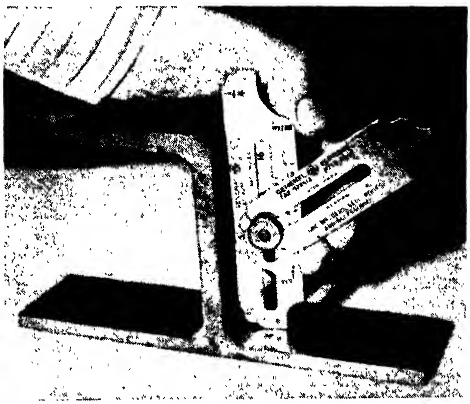


Fig. 123.—A gauge of this type gives the inspector and welding operator a means of accurately measuring the size of fillet welds, which is the first step toward standardization, as well as elimination of the curse of overwelding. (*Courtesy of R. G. LeTourneau, Inc.*)

equal to or greater than that of the parent metal for welded structures using commonly weldable steels. This alone should at least partially answer the question in the minds of inspectors as to the relative strength of weld metal and should therefore prove to them that a fillet joint does not need to be overwelded in order to assure satisfactory quality of end product.

The most satisfactory method of measuring fillet type welds is by using some sort of a gauge that measures the length of the legs of the weld and also the throat, as illustrated in Fig. 123. The use of such a gauge gives positive measurement of the weld and should be a part of the equipment of the inspection department in a welding organization. Careful control of electrode size, arc length, effective welding current at the arc, and speed of travel (with a normal fit-up) on mass production jobs can usually

be depended upon to ensure the correct size and quality of fillet welds.

Visual Inspection of Welded Structures Prior to and during Welding.—The process of visual inspection of a welding operation involves two sets of observations, one while the operation is in progress and the other after the weld has been completed.

Preliminary to taking a welding hood and observing the actual deposition of metal, there are certain things that should be checked. The fit-up of the parts should be normal as determined by the inspector's making a simple examination of the structure being welded and by his knowledge of what a normal fit-up on that structure should be.

It is usually reasonable to assume that the material in the structure is up to proper standards if the control of manufacturing is normal, unless something indicates specifically that the material is not what it should be.

The same applies to electrodes, so far as the quality of the electrodes is concerned, but a glance by the inspector will tell whether the correct type and size of electrode is being used according to the specifications for the job.

It is also assumed that the ground from the work to the machine is properly made in order to facilitate proper welding technique and that the welding machine and power source are what they should be.

The inspector should make a check up on the machine setting by the use of a clip-on ammeter which can be clipped over the welding lead as shown in Fig. 124 and indicates on a dial meter the amount of amperage being used by the operator. This is especially important if there seem to be difficulties with the job such as are usually associated with too high an amperage for welding. It is important that the ammeter be used rather than the ordinary machine-setting indicator on most welding machines, since few of these meters are accurate enough for proper machine setting where close control is being exercised.

After this preliminary check up has been completed and the conditions are found to be favorable, it is instructive to the inspector to take a welding hood and observe the weld actually being deposited.

Such an inspector must know how to "see into" an arc and a pool of metal so that he can observe the way in which the elec-

trode is being manipulated by the welding operator, the length of the arc, the manner in which he is penetrating into the parent metal (getting the arc down into the root of the weld), the amount of fusion (actual melting together and joining of the metal) that he is achieving, the way in which the slag is being worked out of the weld metal, and the way in which the weld metal builds up to the proper size for that particular weld.

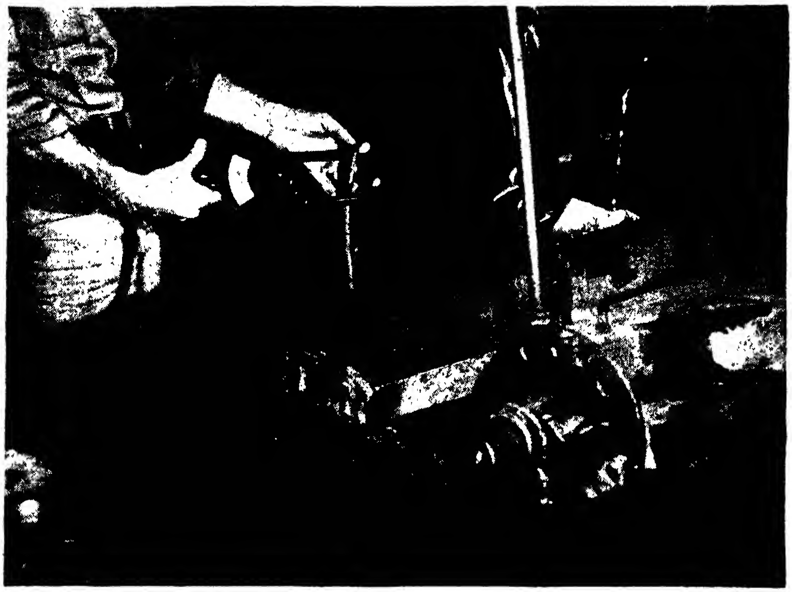


FIG. 124.—This clip-on ammeter shows the inspector or welding foreman exactly what machine setting the welding operator is using and forms a helpful tool for welding control. (*Courtesy of R. G. LeTourneau, Inc.*)

Much can be told by an inspector about the quality of a weld being deposited, even without the examination of the metal being deposited, simply by observing the sound of the welding arc as an indication of proper adjustment and technique. The normal arc should emit a sharp, consistent, crackling sound, free of hissing, sputtering, and whirring and should maintain a steadiness without interruption or special punctuation of any kind.

One of the best indications of a machine setting that is too high for a particular welding job is when the arc is emitting a violent crackling explosive sound and the operation is accompanied by an excessive shower of sparks from the arc. The other extreme,

where the machine is set too low (too cold), is indicated by a weak, pulsating arc that has no "snap" and seems to die down and start up as if the operator were "fighting the arc" or about to "lose" it.

Even if the machine setting is correct, there may be variations in the sound of the arc which indicate that the operator is holding too long or too short an arc for correct welding. A violent whirring or hissing sound emitted from the arc, punctuated by explosive crackles, and also a shower of sparks caused by excessive spatter are indications that the arc is being held too long. The other extreme, where an arc is held too short, is indicated by a subdued steady sound lacking the normal crackle of a correct arc and an occasional sputter as if it were being choked down into the metal itself.

Anyone who really needs to know the details of the different arc sounds as described in the foregoing paragraphs can quickly and easily learn to discern the differences by listening to the welding process being performed with the arc adjustment varied as described. If he can weld himself, he will already have learned to recognize the sounds and interpret them. If he cannot weld, he can learn by a few trips to a welding booth where he can have the welding operator demonstrate these variations, together with the effect on metal deposition that is associated with each.

Visual Examination of the Finished Weld.—A brief examination of the finished weld can almost always give the observing inspector a good indication of its quality.

If he can see the finished weld before the slag has been removed and then remove it, the way in which the slag lies on the weld and the ease with which it is removed almost always indicate something about the quality of the weld. Most mild-steel welding electrodes of the shielded-arc type used today have slag that may be removed relatively easily if the weld is properly deposited.

Slag that is very difficult to remove from the entire weld often indicates that the weld has been deposited at a lower machine setting than should have been used, and therefore that the penetration probably has not been what it should be. In such a case, if there tends to be any slag included along one side of the weld or any pores with slag in them throughout the

surface of the weld, it may be an indication that the weld should be cut out and rewelded because the penetration and fusion probably are not satisfactory.

If the slag clings too tightly to the edges where the weld metal has been fused with the parent metal, the weld should be examined carefully because it probably indicates slightly too

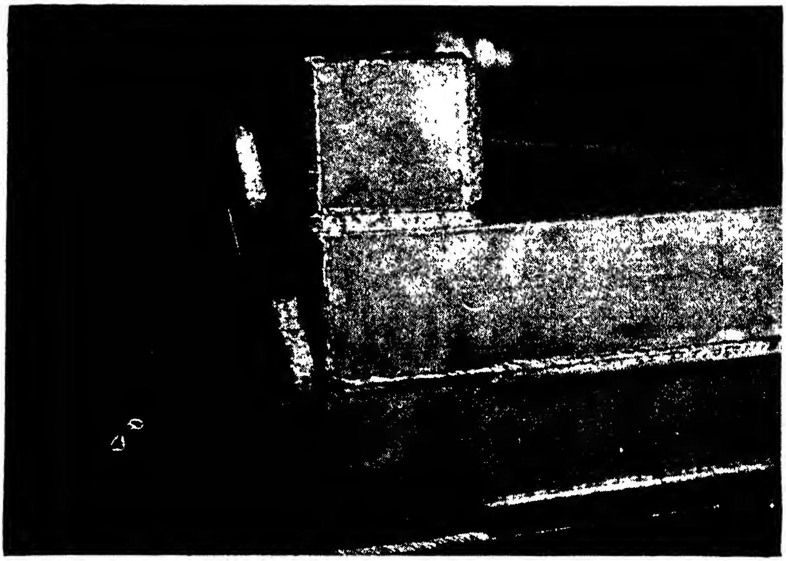


FIG. 125.—Although there are four distinct types of joint preparation (or joint form) and five deposition positions (semivertical, horizontal fillet, horizontal, flat, and vertical) shown here, all these welds have been inspected visually and passed as sound. The trained inspector recognized weld-deposition position and joint type at a glance. (*Courtesy of R. G. LeTourneau, Inc.*)

great a speed of travel or too hot a machine setting which results in a slight undercut. A small amount of undercut is a serious flaw in a weld, because it concentrates stresses and may cause failure at that point.

In case the slag has been removed before the inspector examines the weld, if the margin where it has been removed is smooth and neat and there are no signs of the operator's having done excessive chipping to remove the slag, it is usually an indication of a good weld, especially if the weld itself is free of overlap, undercut, blisters, and porosity.

A glance at a completed weld shows the informed inspector in what position a weld was deposited. Figure 125 shows several

welds, most of which were deposited in different positions. Whatever the position used while the weld was being made on any type of joint, the finished weld should be smooth and free from marked irregularities.

A series of small blisters that come to little pointed peaks in the middle of the weld usually indicate that slightly excessive heat was used in the deposition of the weld. If some of these spots are found to contain slag pockets, it may be advisable to remove and reweld that portion of the weld or to cut out a whole section of it and examine it to see if excessive dirt in the weld or excessive heat or poor material were used to give such condition. Often such welds are more brittle than is desirable for good quality. However, if the weld has only the suggestion of a row of bumps down the center which might look like the little peaks referred to previously, it should not necessarily be looked upon as an indication of a rejectable weld on much commonly welded equipment, because it usually indicates that the arc was "hot" enough to ensure good penetration and probably better fusion than would be obtained with a "cold" arc.

The examination of the features of the weld at the beginning and the end of each part of the weld where each electrode has been stopped and a new one started again is important. These places should be smooth and free of slag pockets in order to indicate the proper kind of a weld.

The tie-ins at the ends and beginnings of the weld, especially where they go into deep corners or connect with other welds, are an important indication of the quality of the welding operator's workmanship. These tie-ins are especially important since they often occur in the structure where there is a natural concentration of stresses and where the best weld possible is most important. The breaking of a weld is like the tearing of a piece of paper; if there is a start of a tear, the paper will tear much more easily. In the same way, if there is poor fusion and poor penetration at the beginning of a weld or at a corner tie-in, there may be a nick effect, like the tear in the side of a paper, that allows the weld to fail more easily.

Importance of a Proof of Procedures.—The most important single step in quality control for arc welding is that of setting up the proper procedure for the welding of the product at the beginning of its production.

It is at this time that the specifications for the size of welds, position in which they should be deposited, type of electrode, number of passes, amount of welding, and all the other engineering factors should properly be described and considered and standards established.

FIG. 126.—The series of stages shown in these test bars, used to prove a butt-joint welding procedure, stress (top) measurement of weld after machining one bar to make the weld fail before the parent metal, (second from top) etch to show passes and fusion, (middle) pull to failure, (fourth from top) force together and measure elongation, and (bottom) examine weld-metal appearance after failure. (*Courtesy of R. G. LeTourneau, Inc.*)

Special tests should also be made at this time of the procedures by destructively examining certain questionable welds, in order to demonstrate that the procedure is adequate before actual production of the unit begins. Such examinations do not require expensive testing equipment or highly specialized techniques, but can be effectively done with the usual machinery to be found in the welding shop if a little ingenuity is used.

In making tests of welded joints, experience seems to indicate that tests of joints themselves, such as the test bars shown in Fig. 126, rather than the all-weld-metal tests on separate and special plates, are most indicative of the welded joint's effectiveness. If a structure is made according to a specific welding procedure and is then destructively examined, and it is found that the

welds are sufficient to satisfy the needs of the design, then the next problem of control is to teach that procedure to the men who will do the job. This teaching operation can be accomplished by the welding symbols placed upon the blueprints, which will give the operators and inspectors information as to just what the procedure is and how it should be done.

Figure 126 shows a series of steps in the simple testing of one butt joint in order to prove a procedure in design. Note that the test specimens are made so that the welds are pulled apart, in keeping with the stress which that particular joint would have

Fig. 127.—By cutting a section across the welds of a test structure after it has been broken and etching the polished section with acid, the fusion, heat-affected zone, number of passes, and cracks produced by the stresses of breaking the structure can be shown. (*Courtesy of R. G. LeTourneau, Inc.*)

to withstand. These tests indicate exactly what this joint would do under the type of stress to which it would be subjected. Note that the test bars were made so that the break would be most likely to occur in the welded joint. Note also the amount of yield and elasticity of the welded joints and that the welds themselves were etched with acid to define their limits in order to observe how they reacted to stressing and breaking.

Another simple method of checking welds on structures where a procedure is being proved is to break a test structure, cut a piece across the welded joint as shown in Fig. 127, and examine it for fusion, penetration, and number of passes. This particular weld test structure shows how the acid etch can be used to prove that it was made in a certain number of passes.

This method of examining welds may be applied in a lesser degree to any weld on an ordinary welded structure where an inspector feels that there is some question as to the quality of the weld. The weld may be cut out with an oxyacetylene

cutting torch along with a narrow margin of parent metal and examined by cutting it in cross sections in order to check the penetration and other features of the weld. One of the big advantages of the welding method of production of machinery is that such a cut out forms a means of checking workmanship where it seems necessary, and it may be patched by simply welding the check hole full with weld metal. Naturally, this procedure will not often be necessary, but it is a means of making the occasional checkup that is necessary in large-scale operations.

The use of X ray, gamma ray, magnetic flux, and such specialized and relatively expensive means of inspection is thoroughly justified on many applications, either as a means of regular inspection or to prove the correctness and quality of first procedures. Yet, considerable amounts of today's welded goods may be manufactured, controlled, and inspected without the use of these specialized testing units.

The importance of the problem of inspection should not be underestimated or minimized; yet, in many cases, the inspection of welded structures may easily be complicated far beyond the actual requirements of that particular structure when the function is considered.

Naturally, the requirements of the specific type of welded product being manufactured by any organization or industry determine the surface appearance requirements, factors of safety, and functional requirements of the welds and, therefore, the type of inspection techniques and devices used in that organization or industry. Before any organization settles on its inspection techniques and devices, however, it should carefully and objectively check a variety of welding procedures on its applications and then, by studying the possible means of inspection, select the simplest and least expensive means available that will effectively guarantee the required quality of the product.

CHAPTER X

THE MACHINING OF ARC-WELDED PRODUCTS

Basically considered, the machining of metal from the raw steel, the castings, or the forgings of a welded structure, either separately or as a finished welding, is not greatly different from most other ordinary steel-machining problems. However, one of the fundamental sources of economy in the use of the arc-welding method of construction for machinery lies in the relative simplification of the machining of the moving parts that make up the machine.

Among the most desirable characteristics of an arc-welded machine is that its main functional parts be fused into a few solid, rigid, functional structures. These working structures, or functional units, of the machine may then be fastened in their proper relationship and function with comparatively few machined parts that are integrally fused into the structure itself and are bolted, riveted, or pinned together so that the machine works as a unified whole.

As an example of this type of simple construction using a few strong welded structures that are held together by a few machined and moving parts, the large earth-moving unit shown in Fig. 128 is representative in that it is composed of a single main body structure to which have been assembled a front gate, a sliding rear gate, a yoke, a push beam, and a front axle structure, all of welded construction and all containing a few parts upon which there has been some machining in order to allow the main welded structures to work in their proper relationship with correct mechanical precision. Figure 128 diagrams the unit and labels in detail the separate premachined parts or structures that are welded into the completed scraper, thus showing its fabrication.

The production of the main framework and structural parts of the machinery does not comprise the only applications of arc welding, since many of the smaller structural parts that go into the main structure and many of the moving parts themselves,

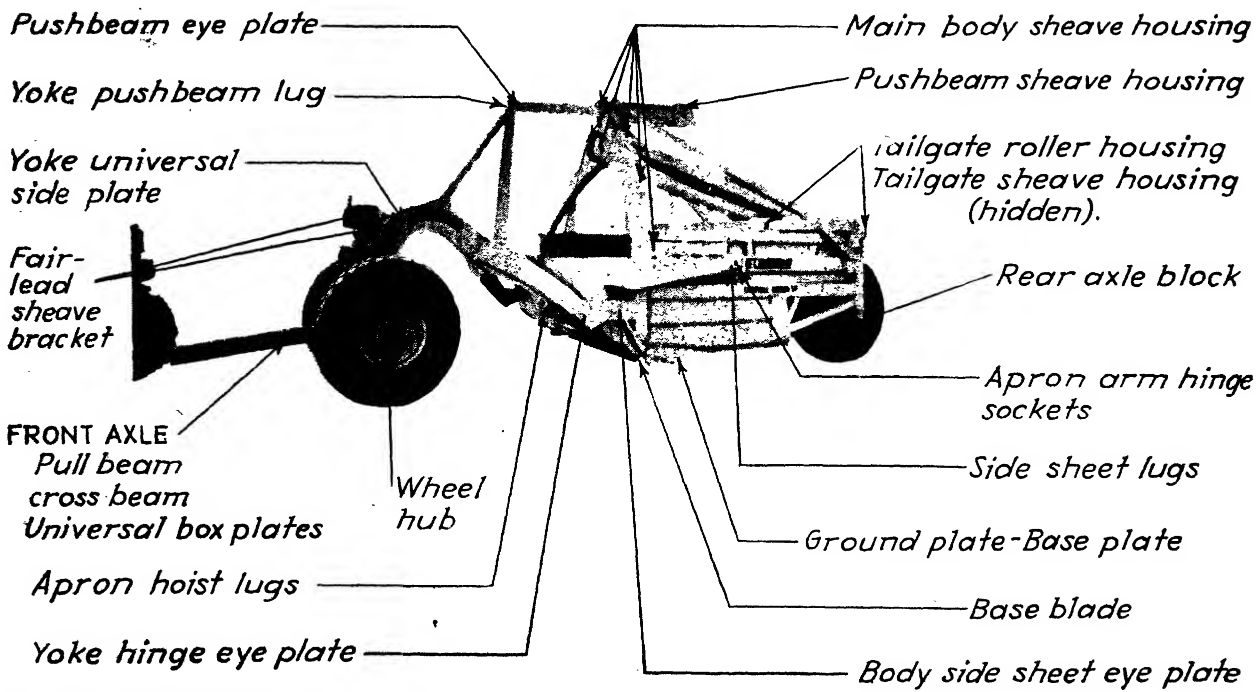


Fig. 128.—A large, all-welded earth-moving unit showing the relatively few machined parts of the machine. Most of these parts were machined as parts or small substructures prior to the welding of the parts into the final structures. (*Courtesy of R. G. LeTourneau, Inc.*)

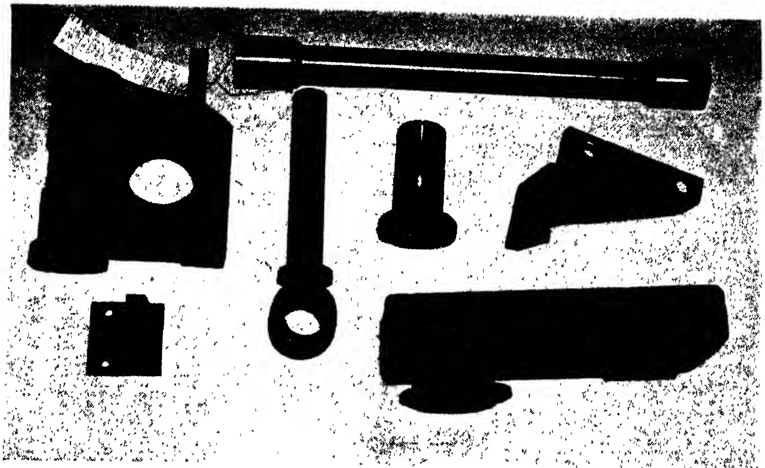


FIG. 129.—These structures are examples of machined weldings, some of which are fast-moving or heavy service units such as the long spline shaft, ground pin, or swivel sheave housing, while others serve as bolt lugs, brackets, or gear cases (lower right) without actually being moving parts. (*Courtesy of R. G. LeTourneau, Inc.*)

FIG. 130.—A rough steel casting (right) and a rough forging, each of which will become a part of a welded structure after it has been machined. (*Courtesy of R. G. LeTourneau, Inc.*)

such as gears, pinions, friction cones, and hubs for wheels, such as shown in Fig. 129, also may be made by the welding method of construction.

The fact that many parts which go into the construction of arc-welded machinery may be machined as small parts, rather than after the whole machine has been unified into its final form (and therefore has become a considerably larger machining problem), presents a valuable source of economy.

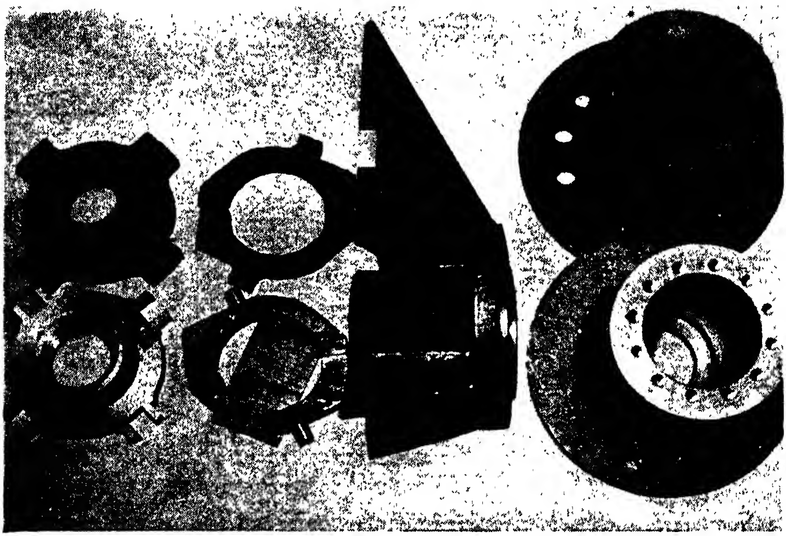


FIG. 131.—Variations in the amount of metal removed in different portions of the same cut are almost certain to be encountered in machining these flame-cut parts and welded structures. These differences in the same cut constitute a machining problem. (*Courtesy of R. G. LeTourneau, Inc.*)

Another source of economy (and a further example of adaptability) of the arc-welding method of production of machinery is that a variety of materials and methods of producing certain functional parts of the unit may be applied, such as the use of steel casting or forgings for certain parts of the machine where the shape, special material requirements, or the cost of the part may justify the use of forgings or castings.

These parts, whether such as those shown in Fig. 130 or those shown in Figure 131, may often be machined while they are still unattached from the main structure into which they will finally be unified and fused by arc welding and, therefore, while they are still much more easily handled and more economically machined.

Extra Material versus Workmanship Costs Prior to Machining. An examination of the parts such as those shown in Fig. 130 or 131 indicates that, perhaps with the exception of the forging, there is likely to be some variation in the concentricity (or thickness of metal to be removed) of the parts that may be machined because of the method of rolling bar stock or flame-cutting plate stock, or both, and combining them into welded structures that are subsequently to be machined.

Either plate rolling or flame cutting from plate, as practiced in the ordinary welding shop on a mass-production basis, is likely to produce parts that are not so uniformly oversize with reference to all surfaces that will be machined as carefully made forgings or castings may be.

The problem of production of such parts, therefore, resolves itself to a certain degree into a problem of the cost of additional material on the one hand as compared with the cost of workmanship that will produce parts having a uniform amount of metal removed from all surfaces rather than considerable variations from one area to the next.

In the production of such heavy machinery as is shown in Fig. 128, the parts are made from relatively inexpensive steel—either ordinary mild structural steel, carbon steel, or even high-tensile alloy steel. In the manufacture of such parts as a fabricated wheel hub made from rolling two bars of steel into bands and welding the bands together, or fabricated gear hubs and rims made in the same way, there is an advantage in the use of a little more material than would be needed to make the parts if they were rolled perfectly concentric and set up perfectly concentric simply because of the relatively greater amount of expensive workmanship and precision machinery that must be used in making the parts in order to roll them accurately concentric in common shop practice.

Frequently, the initial operations (and even the finished operations) of rolling heavy bands are done by pressing them hot in a forming die, where the additional forming required to make them entirely round beyond the first two or three press strokes in the forming operation would cost more than the actual cost of the excess material which is machined off.

At times, the number of parts being made in a production lot by the welding method does not justify the expensive machines,

dies, fixtures, and precision setups for close finishing prior to machining, whereas an order of several thousand parts might justify such a setup.

In the laying out of large members of a structure, a little extra material is good insurance against scrap losses or salvage costs due to parts that crowd the margin of size too closely and will not "clean up" during the machining operation.

By the use of a liberal amount of relatively inexpensive material, the amount of precision workmanship in the original cutting of the part, forming it to shape, setting it up, and actually welding it is considerably reduced. In a welded structure involving three or four separate substructures, and therefore three or four setting-up and welding processes, the additional workmanship required to reduce the amount of excess metal and get a part that will clean up uniformly like a high-class forging may be more expensive than the use of a little more material and normally close workmanship.

Special Machining Problems.—The acceptance of the greatest economy by the use of a slight excess of material in processing for mass production of moving parts for heavy machinery creates a machining problem that must also be considered in the balance of material versus workmanship and precision of the finished part.

In order to obtain the best possible economy in the machining of such parts as are shown in Figs. 130 and 131, a semiautomatic lathe can be used for at least the initial stages of the machining.

In this initial stage on a part that utilizes more material and less precise workmanship of cutting, setting up, and welding prior to the machining stage, there may be irregularities in the machining from a heavy cut on one side to almost no cut at all on the opposite side in the same turning operation.

This presents special problems of maintaining rigid tool-holding and part-holding devices and speedy removal of metal on an intermittent cut basis which are a challenging machining problem as well as an interesting margin for machine design. Especially rigid and rugged machine tools excel on such application.

In order to take full advantage of this type of construction and to facilitate the mass production of such parts, the semiautomatic lathe of all-welded construction shown in Fig. 132 was developed.

This unit consists of a rigid all-welded steel base upon which is bolted a welded gear case (head) that drives a heavy-duty lathe chuck of conventional design. Facing the chuck and gear box, there is an all-welded slide box that contains a traveling quill upon which are mounted the tools, which in their travel forward toward the chuck remove the metal from the part by turning,

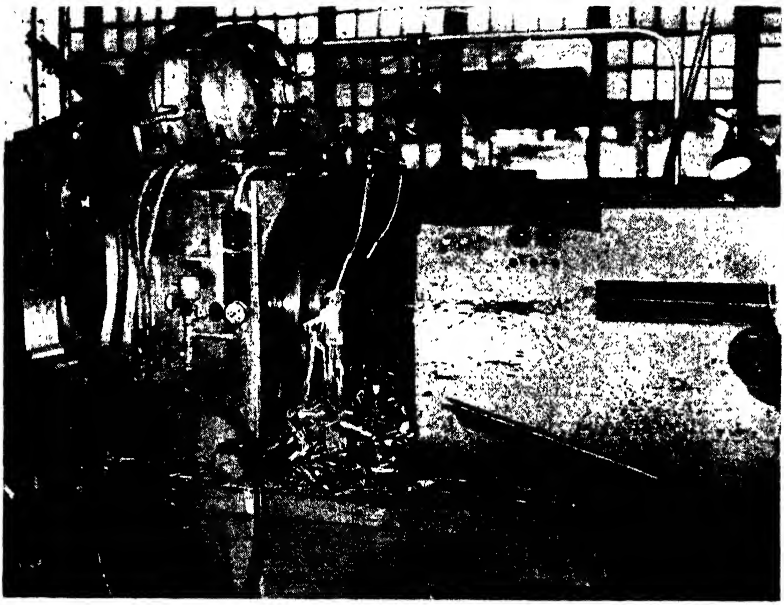


FIG. 132.—This special all-welded semiautomatic lathe drives a 6-in. slabbing tool across a flame-cut part and makes a roughing cut that varies from less than 1 in. to over 4-in. total cut in each revolution of the part. Its rigid and rugged construction allow it to make the cuts quickly and accurately in spite of the variation in amount of metal being cut at different parts of each revolution. (*Courtesy of R. G. LeTourneau, Inc.*)

boring, drilling, or facing. The advantages of rigidity and ruggedness that welding imparts to machinery are the largest source of economy in this semiautomatic lathe, because it gives the high degree of rigidity and strength required to take the best advantage of inexpensive metal removal from parts that have been made with a minimum of workmanship and a reasonable margin of material.

The machining advantage that this type of lathe and construction produces is not confined to welded structures; it also applies to forgings made with a reasonable excess of stock beyond the

finished part, thereby reducing die costs for fine forging contours. It also applies to certain steel castings wherein it is advantageous to remove a slight excess of the metal in order to get under the "skin" of the casting itself and increase the life of the tools used in cutting the part or to use less precisely made and therefore less expensive castings.

For many parts, the machining done in one cut on such a semiautomatic lathe as shown in Fig. 132 is complete enough—

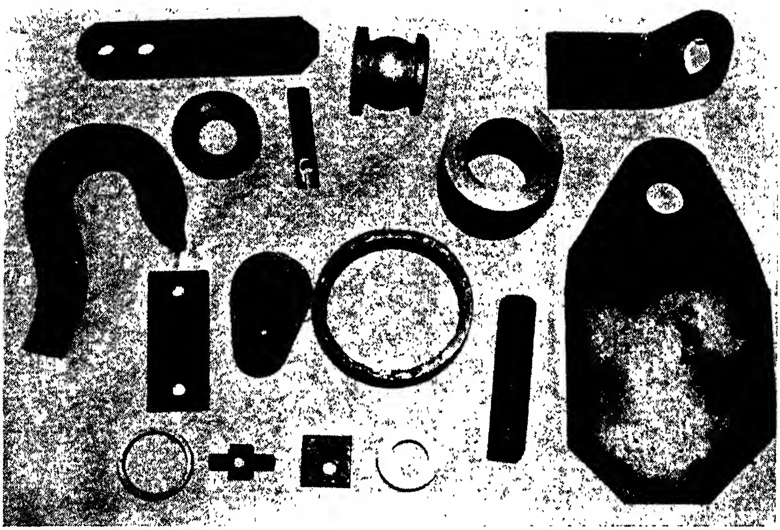


FIG. 133.—These parts are a few examples of premachined parts that will be welded into fabricated structures and will save machining of the entire structure because they are premachined. Note that they are taken from ordinary rolled steel bars, plates, shapes, and tubes. (*Courtesy of R. G. LeTourneau, Inc.*)

to an accuracy of one to two thousandths. Certain other parts may require a closer tolerance of machining which may be accomplished by taking another cut in the same type of semiautomatic lathe, or they may be better adapted to another more conventional type of machine tool.

Premachining of Parts for Welded Structures.—The variety of parts that can be premachined in the manufacture of arc-welded structures is dependent, for the most part, only upon the resourcefulness and the imagination of the designers and manufacturers. Figure 133 shows a few premachined parts cut from

commonly available steel bars, tubes, shapes, or plates prior to being welded into complete weldings.

The economy of premachining parts is obvious from the standpoint of the mechanics of machining. To handle and tool up for a small individual part rather than a large structure requires considerably less labor, machine capacity, complication of holding fixtures, and space for the machining process in general.

The premachining operation may be a roughing process prior to a finishing operation, or it may be a roughing process for parts that will be welded into substructures or completed structures and finish machined in that form.

An advantage of this type of machining is that by rough boring or facing or otherwise machining the parts, setup points of location can be established by machined surfaces that will give positive location and accurate placement in the setting-up fixtures prior to the welding process or to the final machining process.

Since the machined parts usually represent functional contact points in the assembly of a machine, it is essential that the parts be properly located in their correct mechanical relationship, one to the other, during the setting-up and welding process. This is true of forgings, castings, parts made from plates, bar stock, structural members or stampings alike. A machined surface gives a setting-up point that is accurate to work from. It goes without saying that one of the important considerations in welded construction, which goes hand in hand with that of premachined parts, is that of accurate setting-up fixtures for the parts.

Figure 134 is an example of a setup fixture for the location of premachined parts prior to their welding in such a way as to maintain accurate relationships between widespread functional points of the machine.

One of the big advantages of the premachining of parts is that they are usually of a homogeneous nature during the machining process and therefore do not present the problems of machining parts that have, because of welding or other treatment, been rendered variable in structure in such a way as to interfere with machining.

This homogeneity of parts is a considerable advantage; for many of the machining operations on ordinary premachined parts are the common drilling, boring, turning, reaming, milling,

broaching, or hobbing operations where homogeneity of material results in a considerable amount of saving of tools and simplification of setting up and holding the work.

Usually the parts start as a simple piece of round, square, rectangular, or odd-shaped stock, cut from plates or bar stocks,

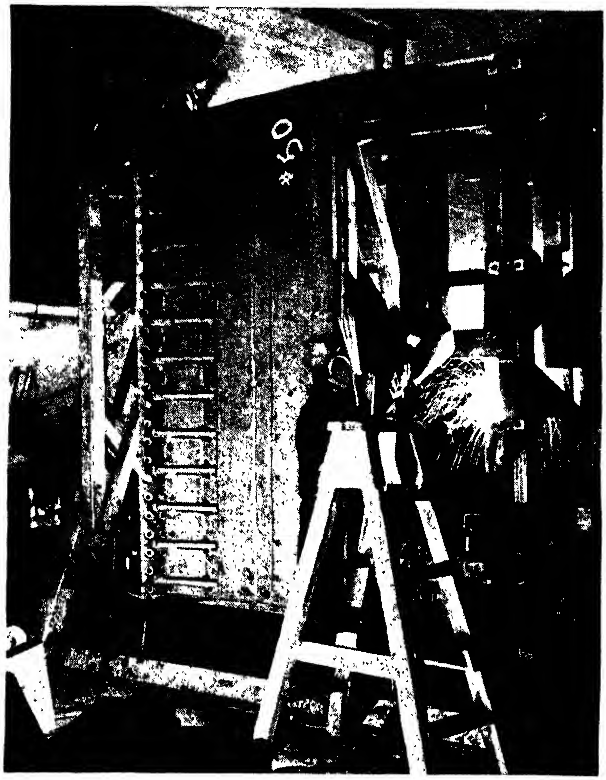


Fig. 134.—The relationships between the premachined and therefore important functional parts of this large earth-moving scraper body must be maintained accurately and positively. The machined surfaces of premachined parts fitting accurately to correctly placed stops on the setup fixture assure proper alignment without machining the whole structure. (*Courtesy of R. G. LeTourneau, Inc.*)

without further shaping or treatment prior to the machining operations.

Caution must be exercised, however, in the machining of flame-cut parts from high-carbon (over 0.35 per cent) or alloy plates or structures, because of the fact that the heat of the cut, which is immediately quenched from the mass of the material surrounding

the cut after it is completed, causes a chemical segregation in the high carbon steels and in many alloy steels that forms a hard region immediately around the flame-cut area.

There are two ways of assuring freedom from varying hardnesses around flame-cut areas which will be damaging to the machining process either from the standpoint of accuracy or of broken tools. The first and most positive is the normalizing of the piece (heating it to 1200°F. for ordinary structural steel and allowing it to cool, either in the air or in a furnace, depending upon the analysis of the part). The second method is that of removing a deep enough cut in the neighborhood of the flame-cut area to get under the hard segregated area and, therefore, machine it free from the part without breaking tools.

Machining Welded Substructures.—In the same way that the parts may be cut and premachined, so also may substructures be fabricated and machined prior to being welded into the final structure.

The combining of different sized rounds, squares, billets, structural members, or plates to form bearing blocks, housings, machine bases, or other substructures offers an economical way of placing masses of material where they are needed for structural or functional purposes without incorporating the massiveness of taking them from large solid bar stocks, forgings, or castings.

The machining of welded substructures presents one additional problem over that of machining parts. The problem is similar to that of machining flame-cut parts, *i.e.*, heat-affected areas on the substructures due to the heat-affected areas near welds. Still another problem is that of locked-up stresses from the welds themselves upon the substructures, which may cause distortion, or may cause the parts to shift out of shape in the machining process because the locked-up stresses are relieved by the removal of some of the metal in the structure.

Figure 135 illustrates the condition sometimes encountered in the locality of a weld in high-carbon steels or alloy steels that have not been normalized, or stress relieved. If the area is cut into in the process of turning, boring, or milling or the other common machining processes, this condition may cause serious breakage of tools.

On ordinary low-carbon structural steel, or steel of the SAE 1010 to 1030 classes, welds and the welded locality usually are

machinable without serious difficulty if an ordinary welding electrode has been used.

In the welding of alloy steels or high-carbon steels, or in the welding of structures wherein the stresses set up by the welded joint may cause distortion in the machining process, the normalizing of the parts is a good safety measure in order to avoid

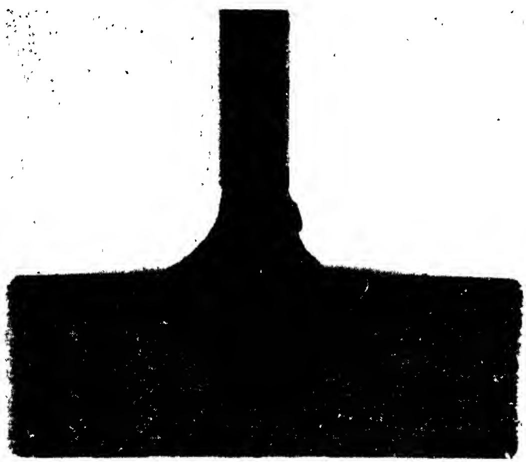


FIG. 135.—A section of a welded T joint that has been removed, polished, and etched to show the heat-affected areas at the margins of the welded areas. These areas (light colored surrounding dark weld metal) are likely to be hard if the steel is high carbon or alloy and may cause broken tools or irregularities in a machined finish unless they are avoided or removed by normalizing. (*Courtesy of R. G. LeTourneau, Inc.*)

broken tools or scrapped structures that have sprung out of shape when the stresses were relieved by the removal of metal.

In the welding of high-carbon steels (carbon 35 per cent and up) that will later be machined, it is often a worth-while practice to weld the structures hot, because it aids in the prevention of broken tools which might result from not normalizing the structures, and also because the welding operations often proceed much better hot than at normal temperatures.

Even if machining operations are not performed in the immediate vicinity of the welds, it is often a worth-while operation on high-carbon welded substructures to normalize them in order to prevent tool breakage that might result from hard spots. These spots may be caused by such simple things as a

workman accidentally striking his arc or scratching his arc over the surface of the structure where it will be machined. Such a scar from the arc, although it may be very small, is sufficient to cause a hard spot large enough to break a tool or leave a flaw in the machined surface.

FIG. 136.—Welded structures or steel parts may often be salvaged by building up the oversize bores or padding up the areas that will not clean up, are turned too small, or are too close to holes. These structures can be remachined and thus salvaged for much less than the cost of making the part over from the start. (*Courtesy of R. G. LeTourneau, Inc.*)

Welding as a Means of Repairing Machining on Structures.—One of the important advantages in the use of steel and the arc-welding method for producing structures, aside from strength, is the fact that during the machining process if a hole is drilled in the wrong place, a bore is made oversize, or some other machining operation is mistakenly done, it is often possible to build up the machined surface with weld metal and simply remachine the part. Figure 136 shows several parts that have been salvaged in this manner.

If the part is made of mild steel or low-carbon steel (SAE 10 to 30), it is usually possible to weld on it with an ordinary AWS E 6010 or E 6020 welding electrode and build up a pad of metal that can be machined without normalizing.

This method of salvaging small parts and substructures is an effective means of reducing the amount of scrapped parts or substructures. It not only is effective for parts and substructures, but at times presents a great saving in the correction of mistakes on the machining of large structures that involve a large investment of material and workmanship. It is not impossible to weld up such a mistake in machining without even removing the structure from the machine in which the work is done.

Use of Welded Jigs and Fixtures for Machining Structures.—For welded structures upon which there is a large amount of machining, or where close tolerances of machining must be held when producing the units in large numbers, the use of machining fixtures consisting of a framework made by arc welding, upon which are welded stops, is a means of accomplishing the machining without expensive individual laying-out processes on the welded structure.

For units such as gear cases, or even simple plates or structures where there are holes to be drilled, reamed, or bored, the building of a simple drilling jig into which hardened and ground bushings are inserted (thereby positively locating the holes) and upon which are stops or other means of locating the part with reference to some special surface greatly increases the speed with which such parts may be processed in the machine shop.

The fact that welded structures almost always have some flat area of rolled plate or some other regular surface that may be used as a reference point against which the stops of a jig on a fixture may rest and locate holes makes the manufacture of such fixtures and jigs by the welding method a relatively easy procedure.

Naturally, the complexity of the unit that is being machined determines the type and complexity of the fixture. For the machining of complex gear cases, it may be necessary for more than one fixture to be made, whereas in the machining of a simple lug, bolt plate, or bracket, the fixture may be much simpler.

Figure 137 shows a complex fixture used in machining the main gear case for a cable-operating power-control unit that is mounted on the rear end of a tractor. The fixture is of the "roll-over" type and may be indexed about a central axis so that a variety of drilling, boring, and counterboring operations may be done on the case with a minimum of measuring, laying out, and handling.

The machining of this gear case is done on a radial drill, and a drilling fixture employing hardened bushings and welded-on stops may be observed to the right of the radial-drill column.

Machining Large Arc-welded Structures.—The machining of any type of large structure is more complex than that of a simple one. With the application of arc welding to the manufacture of gear cases, engine bases, engine blocks, large presses,

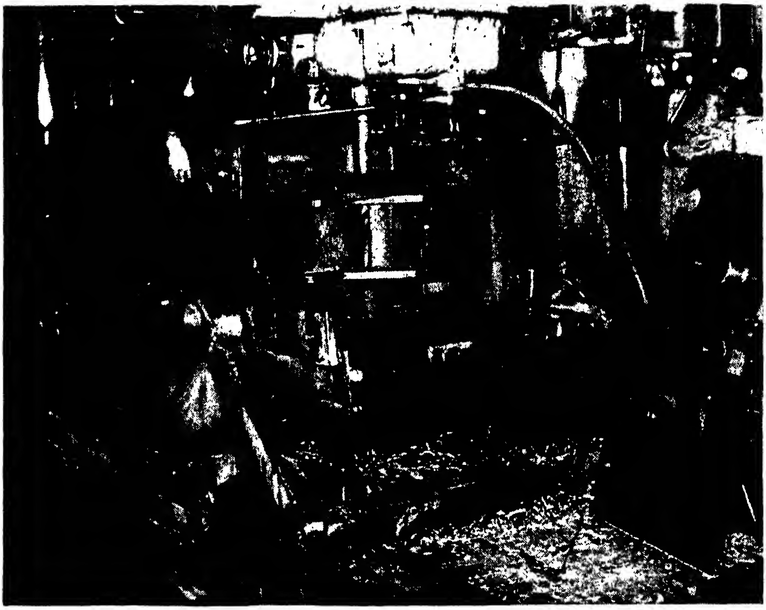


FIG. 137.—A "roll-over" type special welded fixture for machining a power-control unit frame, gear case, and bolt plate structure. This fixture facilitates machining by reducing setup time, layout, and handling. (Note drilling jig with welded stops and hardened bushings at right.) (*Courtesy of R. G. LeTourneau, Inc.*)

lathes, and other complicated machines upon which the tolerances must be held closely and wherein the structural strength must be of a high degree of reliability, this complexity is increased.

A large gear case with a large amount of welding upon it, such as is shown in Fig. 138, in most cases should be stress relieved or normalized, especially if it involves the use of high-tensile alloy steels, in order to avoid the distortion of the machined structure by the release of stresses from removal of metal and to avoid hard spots that cause flaws in the machining.

It is not always necessary to normalize gear cases and many other relatively simple structures that are designed in a box shape and are, therefore, rigid because of their structural shape and upon which there may be welded bearing blocks that confine their stresses to a relatively well-balanced stress within a certain portion of the gear case. Whether or not the gear case or welded

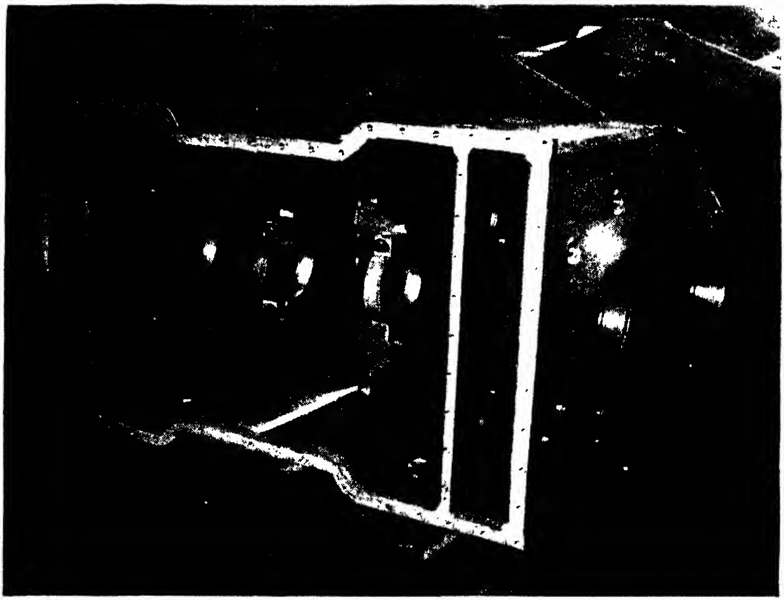


FIG. 138.—This 1,700-lb. all-welded gear case is an example of an arc-welded structure that allows close, accurate assembly tolerances to be maintained with a minimum of machining upon the case itself. It is normalized prior to machining. (*Courtesy of R. G. LeTourneau, Inc.*)

structure that requires some machining upon it after it has been completed should be normalized depends largely upon the amount of welds on it, its general shape, the amount of stress that will be placed on the unit in operation, and the heat at which it will operate. If there were great locked-up stresses on a structure that operated at a temperature of 200, 300, or 400°, those stresses would probably be relieved and might cause misalignment of working parts inside the case because of changes in the alignment or form of the case itself.

In the example of the large tractor transmission case shown in Fig. 138, because of the close tolerances to which it must be

machined, the heat at which it operates, the large amount of welding on it, the curved design of its body, and the fact that there are alloy steels used in the case, it is necessary to normalize the welded case before machining it.

One important source of economy and convenience in the machining or manufacture of such structures as the gear case shown in Fig. 138, using alloy steel in the frame of the case, is

FIG. 139.—When the fuel tank and motor-frame structure are set up and welded to the machined gear case (see Fig. 138) in this fixture, the 25 ft. of welding does not seriously stress or distort the case because of its rigid, boxlike design. (*Courtesy of R. G. LeTourneau, Inc.*)

that many parts which must be machined (such as the heavy bearing blocks upon which the axles of the tractor operate) may be made from low-carbon steel which is more easily machinable and less expensive than the alloy steel used in the case. This differential designing, using special materials for special functions in the same structure, tends to a better design than can be accomplished by almost any other means. It also imparts a degree of convenience in machining that is a great advantage.

Welding Parts to Machined Structures.—After a gear case, transmission case, or other relatively complex welded structure

has been machined, it is often possible to weld other structural or premachined parts to it or to weld it into a more complex structure without causing serious distortion or otherwise hindering the function of the finished structure.

An example of such welding is shown in Fig. 139, where the highly machined main transmission shown in Fig. 138 has been unified by arc welding with the combined fuel tanks and motor-hanger frame structure (also of arc-welded construction) to form the complete transmission case, engine hanger, and fuel-tank assembly for the tractor.

In this example, the rigidity of the welded case plus its box construction and well-reinforced cross-member (inside bearing block) reinforcements make a sufficiently rigid unit so that to weld the major part of the tractor frame to the front side of the case (a process involving approximately 25 ft. of welding on the case itself) still does not draw the case out of shape to the extent that it interferes with the function of the case after a small amount of hand reaming has been done in the final assembly, prior to the installation of the main bearing cups.

The welding on of actuating lugs, reinforcements, mounting supports, and a large variety of other features that might be arc welded to welded structures that have been machined can be done without interference with the function of the unit as long as care is taken to study the effect of the welding and, wherever necessary, to apply the technique of making short intermittent welds and allowing them to cool, to minimize distortion. Another method is to design in such a way that the welds required to fuse the parts to the welded and machined structure balance each other so that they tend to equalize the stresses, in the same way that flame hardening is frequently applied to both sides of a long narrow section (such as lathe ways) in order to equalize the distorting effect of the heating and maintain the straightness of the structure.

By fully utilizing the elasticity afforded by the premachining of parts and substructures, and by welding additional parts to completely machined weldings, the efficiency and economy of the arc-welding method of production of machinery can be realized.

CHAPTER XI

CLEANING ARC-WELDED MACHINERY PRIOR TO PAINTING

Few steps in the manufacture of arc-welded machinery are deserving of more care and attention than the cleaning operation that prepares the machine for its protective covering of paint, yet frequently it is a step that is hastily and incompletely done. This is particularly true of welded structures on which the welds receive no grinding or special finishing prior to the final covering with paint.

The preparation of fabricated machinery for its first coat of paint automatically sets the standard of the appearance and controls the life of the machine to the extent that it protects the surfaces from the ravages of corrosion. Usually, if the first protective cover breaks down, successive covers are short-lived, unless the first is completely removed—a process that is too expensive or laborious, under most conditions, to be considered practical.

There are probably many reasons for imperfectly cleaned weldings. It may be that an incomplete understanding of all the factors involved in such cleaning processes is the primary reason for the breaking down of the protective paint covering on welded structures such as the one shown in Fig. 140.

This structure was welded and machined and then given a thorough brushing, hand chiseling, and in addition a washing to remove the oil and other foreign matter that it had accumulated during the fabrication and machining. This was followed by the application of two coats of paint.

In spite of this apparently complete cleaning process, the paint failed badly within six weeks, and the most serious failure occurred on and near the welded joints.

The reason for the failure is that the cleaning of an arc-welded structure is fundamentally both a physical cleaning and a chemical cleaning process, and often one or the other or both of

the processes are incompletely done. In this case (Fig. 140), the structure was not chemically cleaned properly before painting.

The steel from which the structure is made usually has some scale, dust, and other foreign matter on it when it is taken from stock and prepared for welding. The cutting, shaping, pressing, machining, and handling of the parts before the actual welding process almost always leaves them with oil and grease spots on

FIG. 140.—The dark fringes along the welds on this wheel are spots of rust which indicate the breakdown of the paint on and near the welds. (*Courtesy of R. G. LeTourneau, Inc.*)

them, often increases the scale and dust accumulation, and often results in some degree of rusting. To this, the welding process adds the rippled surface of the welds, a variable amount of slag that adheres to the weld beads, a quantity of spatter drops (the spray of globules of metal emitted by arc explosions), and a smoky, dusty, deposit of chemicals that were vaporized by the arc and condensed on the plates adjacent to the weld. The structure shown in Fig. 140 received a passably good physical cleaning but not a sufficient chemical cleaning.

Physical Cleaning First.—A thorough physical cleaning is the first part of the cleaning process. The type of equipment used varies with the size and nature of the structure, but the object of the process is to remove from a welded (and, in many cases, a

machined and assembled) structure the slag, spatter drops, dust, scale, and other foreign matter that adhere to the surface and interfere with either the coat of paint or the desired physical appearance of the completed structure.

Figure 141 shows a part of the main body of an all-welded earth-moving machine as it appears before the cleaning process starts. It was first brushed clean with a power buffer to remove

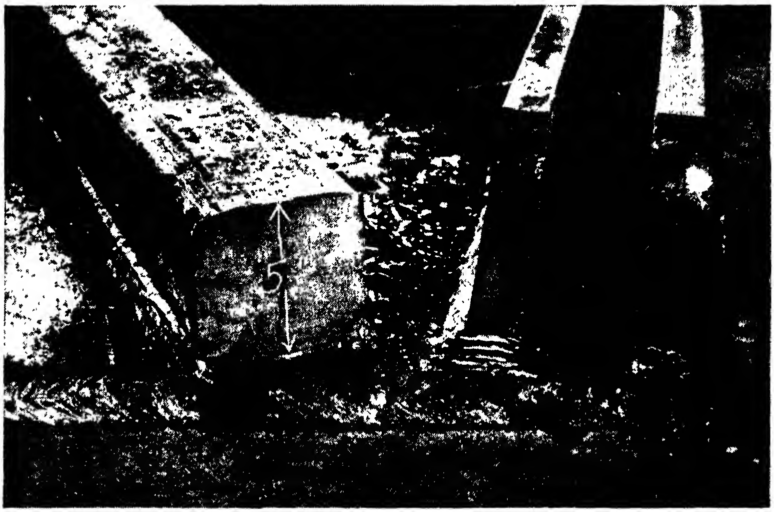


FIG. 141.—A thorough physical cleaning removes the slag, dirt, and spatter drops from this structure and prepares it for a chemical cleaning. (*Courtesy of R. G. LeTourneau, Inc.*)

dirt, scale, spatter drops, globules, and slag. In deep corners and tight places where a power buffer could not reach all the surface, a stiff wire brush was used. Strong sandblasting or grit blasting of the whole unit, with special attention to the welds, is a more satisfactory method of cleaning than buffing if a sandblast room is available, since it is faster than buffing and does a more thorough job. After the brushing or sandblasting, there are fragments of slag that cling to the welds, large spatter drops that have fused with the surface of the welds, and sometimes the remains of small tack welds left after tacking small temporary spacers to the structure prior to welding. These are removed from the structure with a light air chisel, or with a hand slagging tool, leaving the structure as it appears in Fig. 142. The surfaces

are then as free of irregularities and rust and scale as is necessary for such a piece of machinery and the structure is ready for the washing that will prepare it for the first coat of paint.

Structures that are welded and then stress relieved and machined, such as the transmission case shown in Fig. 143, present a somewhat more complex cleaning problem. A sand-blasting or shot blasting prior to machining removes the scale and most of the adhering slag and spatter drops. A hand- or

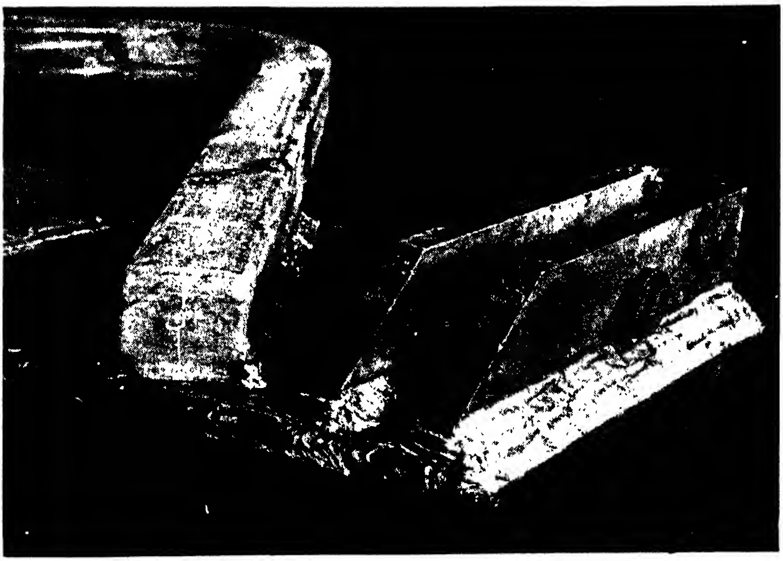


FIG. 142.—The same structure as shown in Fig. 141 after the physical cleaning process. Note the many small ripples, weld joints, and tight fits which may harbor chemical deposits from the welding process. (*Courtesy of R. G. LeTourneau, Inc.*)

power-chiseling operation completes the cleaning off of the solid foreign materials that have to be removed before painting. After the structure has been machined, the oil and the accumulated dirt and chips must be washed off as part of the chemical cleaning.

Physical cleaning of small welded parts, either plain or heat-treated, usually can be effectively accomplished by hand or power brushing or blasting with shot or sand, whichever method is more easily available or proved by study to be the cheaper, followed by chiseling to remove spatter drops and slag fragments.

Chemical Cleaning Necessary.—Welded structures that are cleaned by brushing or blasting and touched up by chiseling, such as the one shown in Fig. 142, still harbor compounds that must be removed before a lasting paint covering can be applied.

Almost all electrodes leave a deposit of chemicals along the margins of the welds wherever an arc has touched the plates

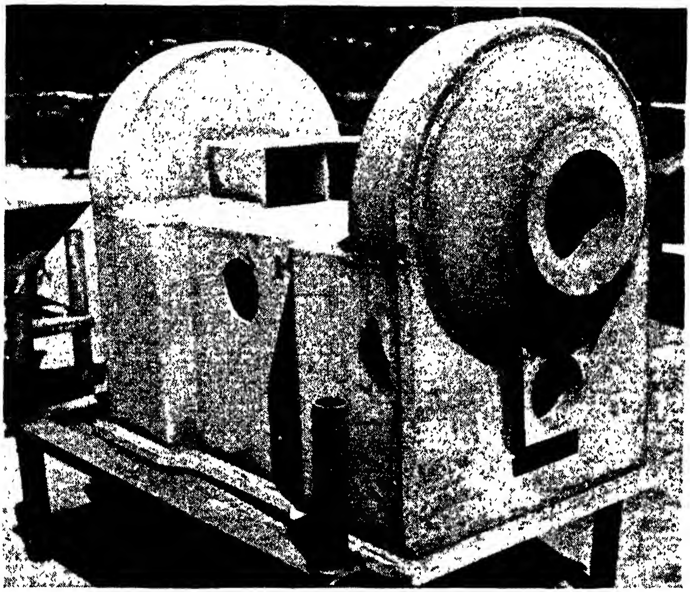


FIG. 143.—This transmission case with its complex shape, numerous welds, scale from normalizing, and the oil it will pick up during machining presents a more varied cleaning problem than a simple welding. (*Courtesy of R. G. LeTourneau, Inc.*)

during the welding. In almost every case, there are soaplike compounds in the deposit that are strongly alkaline. In some cases, these chemicals are present in a large enough quantity and are sufficiently hygroscopic to absorb moisture from the air and even form a dark, oily-appearing margin along each side of the weld within 2 to 12 hr., especially in humid, warm weather.

One simple test that shows the alkalinity of the arc-fume deposit is to apply a moist paper or finger to the smoke deposit along a weld and then taste it. It almost invariably tastes soapy (alkaline). Figure 144 shows the result of a more sensitive test for this alkalinity.

The weld on the plate is entirely comparable to any weld on the cleaned structure in Fig. 142. The slag, dust, arc smoke, and spatter drops were brushed and chiseled off. An ordinary chemical filter paper was dipped in a solution of distilled water containing a few drops of 1 per cent solution of phenolphthalein in alcohol and then gently pressed down on the surface of the weld and adjoining plate. The dark margin on the filter paper (Fig. 144) over and near the weld is the pink coloring caused

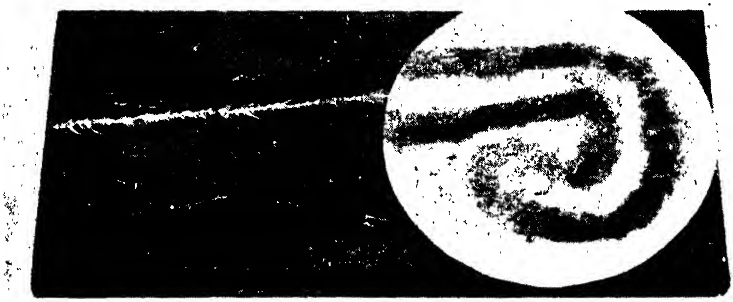


FIG. 144.—The dark cloudiness in the paper disk along the weld is caused by a 1 per cent solution of phenolphthalein in water, turned red by the alkaline chemicals deposited on the plate by the arc. These chemicals cannot be brushed off and will cause premature breakdown of paint coverings unless removed by chemical cleaning.

by the reaction between the phenolphthalein and the alkaline compounds left from the arc. It was these compounds that were not removed from the structure shown in Fig. 140 before the paint was applied; and it was these compounds that caused the paint covering to break down and rust spots to appear within a short time.

The chemical cleaning must remove the alkaline compounds on welded structures if a lasting paint cover is to be obtained. It may be possible to apply enough coats of paint to cover up these compounds; but they are usually sufficiently hygroscopic to have drawn some moisture from the air, thus giving the paint a tendency to slip and peel easily. The thicker the coat of paint, the easier it seems to peel off if there is moisture or an alkaline residue from welds under it.

A simple washing with water or some solvent that will also dissolve the oil and grease from the structure is usually not

sufficient to remove enough of the alkali to ensure a lasting paint coat.

A wash, or a series of washes, that will neutralize the alkali and carry most of it away in solution and a wash to remove the grease and oil and leave the surface of the metal dry and ready for the paint are required.

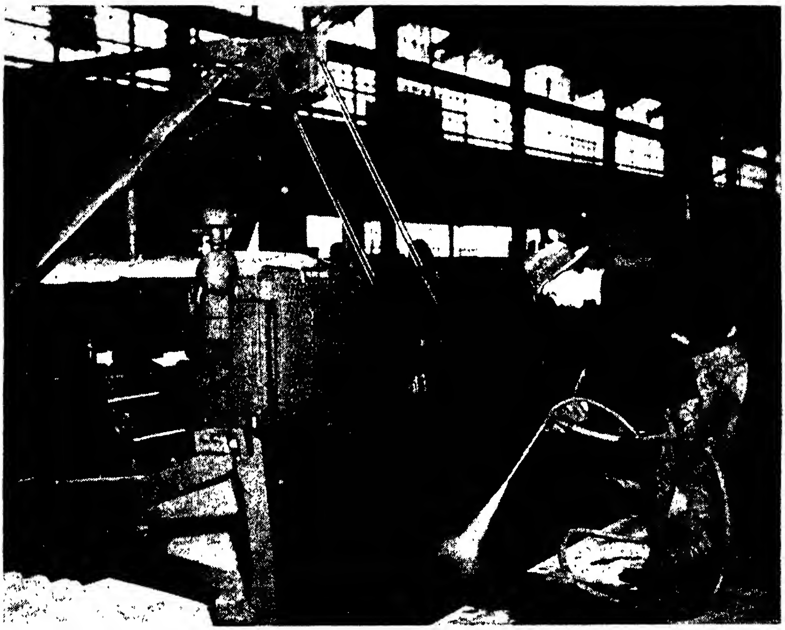


FIG. 145.—One of the best ways to apply cleaning agents to welded structures prior to painting them is by spraying. This large, tractor-mounted all-welded earth-moving unit can be thoroughly washed from the floor by spraying in a few minutes. (*Courtesy of R. G. LeTourneau, Inc.*)

Steam cleaning can be employed to remove oil and grease. In the case of manufacturers of products requiring pickling processes to give the unit (finished) a high degree of smoothness, the pickling process removes both the alkali and the grease.

For ordinary welded structures that are not pickled or especially greasy, there are several chemical cleaners on the market that are prepared to neutralize the arc-smoke deposit and function as satisfactory cleaning agents. The best consist of a solvent such as naphtha, mineral spirits, or oleum spirits combined with an acid agent that will neutralize the alkali residue. Some are

an acidified water solution. The application of such washing agents may be done in several ways, but the one shown in Fig. 145 is among the best.

Since the function of the wash is that of removing dust, oil, and other such residues as well as wetting the whole surface (especially adjacent to the welds) to chemically neutralize and sluice off the alkali, the application of it as a spray has some significant advantages.

Spray applications save much of the labor involved in brushing and also save the cost of brushes, which is an important item if 3 or 4-in. standard paint brushes or other high-quality brushes are used.

Studies of brushing on cleaning materials or wiping them on with cloths compared with spraying indicate that less material is usually used in the spraying-on process.

Another advantage of spraying on such cleaning materials is that the workman does not have to get his hands in the cleaning agent nor does he have to work so close to it that his clothes get wet or soiled.

Inspection and Control of Cleaning.—The control of cleaning processes on welded structures and the exact specification of the degree of cleanliness required to pass inspection present several problems. However, it is important that such control be exercised in the interest of economy and uniformity of the finished products. The type of unit shown washed in Fig. 145 represents the large class of welded machines that are cleaned "as welded" after fabrication and assembly.

Probably the most important step in controlling the amount of blasting or buffing done is that of telling the operator how far to go in such a way that he can consistently complete the cleaning job to a certain standard and then go no further.

It is almost a universal human trait to overdo a job such as cleaning, rather than to do less than is called for. This arises from the natural and commendable desire on the part of almost everyone to do a job that cannot be criticized.

In cleaning welded structures, the best results seem to be produced if the workman is instructed to concentrate on the welds and weld margins, since it is there that he will find slag, spatter drops, and most of the rest of the materials that are associated with welding and that are difficult to remove. On

much welded machinery, such as that shown in Fig. 146, if the welds are properly cleaned there will have been sufficient cleaning done so that the effects of the cleaning (blasting or buffing) process will have spread over and adequately cleaned the surface of the steel parts joined by the welds.

The grinding of welds to make them smooth and free of ripples, such as is done on some types of welded structures, removes the slag and irregularities from the weld itself but does not always

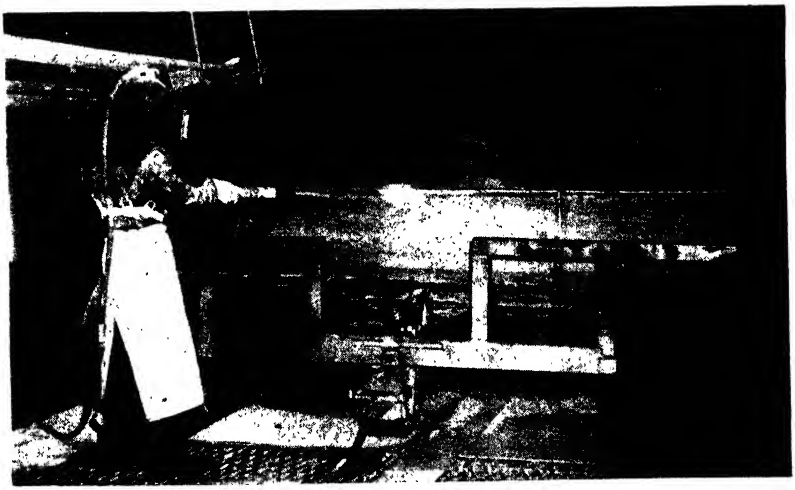


FIG. 146.—On equipment such as this, if the blaster directs his blast upon the welds properly, sufficient cleaning will have been done when he has finished. (*Courtesy of R. G. LeTourneau, Inc.*)

remove the spatter drops from the areas immediately adjoining, nor does it eliminate the need for chemically cleaning those areas.

The problem of just how much brushing or blasting shall be done by the man who does the preliminary cleaning and how complete a job of scraping off the spatter drops and slag flakes shall be done has been helpfully defined by the use of cleaning specimen plates such as the one shown in Fig. 147.

The plate (Fig. 147) marked off in three segments has been welded in such a way as to cause large spatter drops and a wide, flat bead in the as-welded state, shown in the section on the left. The central section shows a partial job of cleaning that will not pass inspection because of the numerous spatter drops remaining of the plate. The section on the right end of the plate represents the cleaning job that will pass inspection.

This type of specimen plate is posted in the department and can be used by any workman to compare with his job of cleaning and can be used by the inspection department as a specification for completeness of cleaning. Pictures of the plate are filed in the inspection department as a master specification to assure a

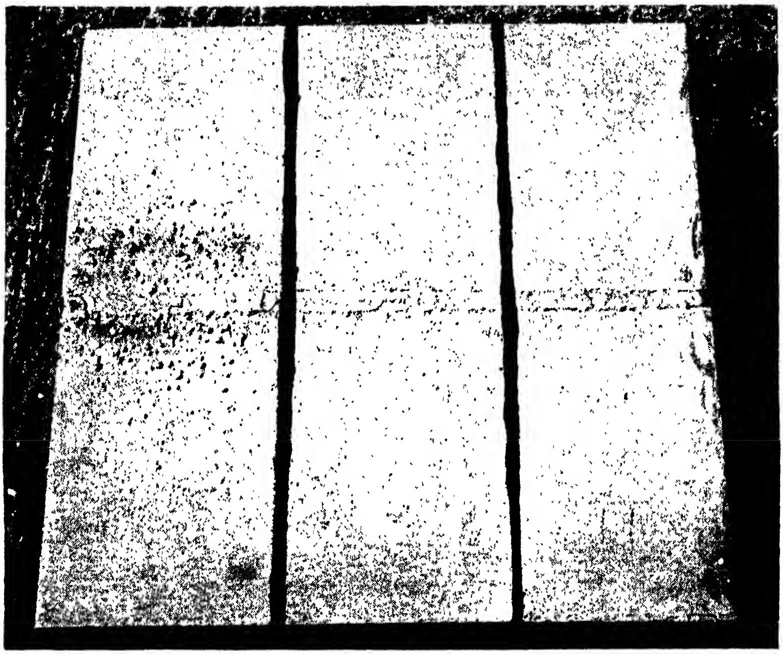


FIG. 147.—This standard weld-cleaning comparison plate shows workmen and inspectors on the job, an uncleaned portion (left), a partially cleaned portion that will not pass inspection (center), and a passably cleaned structure (right). (*Courtesy of R. G. LeTourneau, Inc.*)

uniform standard of cleaning over a period of time. Control of the physical cleaning process is materially assisted by the use of such plates.

Another means of controlling the amount of spatter drops that are removed or left on a welded structure is to use a berry-picking tool such as the one shown in Fig. 148 and to simply specify that "all berries removable with the tool shall be removed and the rest are to be considered unimportant." The narrow end may be designed to clean narrow surfaces and the wide end to clean the wider areas. Naturally, the use of such a tool as a

means of control is limited to a type of welded product that does not require a 100 per cent clean surface such as would be necessary for the outer parts of an automobile.

The control of the chemical cleaning lies in the thoroughness of the inspection after the final washing is completed. It is not difficult to tell where places have been missed in the washing process. If the cleaning compound has the chemical strength it should have, a place that is washed free of grease and dust and has been thoroughly wet can be considered clean.

FIG. 148.—With correct design to give a certain quality of spatter-drop-free surface, the exclusive use of this type of tool with the order "remove all berries that can be removed by the normal use of this tool" provides an effective spatter-drop cleaning-process control. (*Courtesy of R. G. LeTourneau, Inc.*)

A good inspection of all parts of the unit just prior to the application of the first coat of paint is certain to be a profitable investment of time and effort, because it not only serves to control the appearance of the finished product by reducing the number of spatter drops, slag chips, etc., left on the surface to a predetermined minimum, but it also assures a lasting protection from corrosion and a favorable appearance of the unit by ensuring a complete removal of the chemical elements associated with arc welding that cause paint coverings to break down prematurely.

Normally, the welded structure that has been cleaned properly for painting should be painted as soon after the cleaning process as is practicable. If the structure has been thoroughly cleaned, any paint that is applicable to steel products will serve well.

CHAPTER XII

TRAINING ARC-WELDING OPERATORS

With the development of arc welding as a major means of producing equipment and machinery, there has been a corresponding need for the training of large numbers of welding operators. Many of these men have gradually developed into arc-welding operators as an outgrowth of their previous work as mechanics, and a yet larger number have been specifically trained for some phase of arc-welding construction.

The development of arc welding has been so diversified and the machinery and materials have been so specialized for certain fields of work that there is a great deal of variation and specialization on the part of welding operators for different parts of the industry.

With the development of mass-production arc welding, a large group of welding operators has been trained whose main function is that of simply operating a welding arc and depositing welding metal, often in a specialized way. This may be simple from the standpoint of the training required to do the job in many cases; it may, on the other hand, be a highly skilled craft in some other types of work.

During the past two or three years, a tremendous number of arc-welding operators have been trained to deposit metal on a mass-production basis to be employed in shipbuilding, aircraft production and various phases of automotive production for military use.

The welding operators used in the future, as in the past, will be drawn from the already available welding operators or new trainees.

Specific Training Needed for Each Organization.—In either case, whether an already trained welding operator is hired to work in a specific organization, or whether an inexperienced man is employed for training to be an arc-welding operator, there must be specific training given to the newly hired operator. This almost always must be actual welding training.

This also is usually true for arc-welding operators who have been trained in schools outside an organization from the beginning of their training period until they are presumed to be ready for employment in some factory.

The reason for this special training lies in the fact that every producing organization has somewhat different practices and procedures; and a special product, though it may be similar to other units manufactured by the welding process, is always manufactured slightly differently in different plants.

Some of these differences lie in actual weld-deposition practice, which often makes it necessary for experienced welders or inexperienced trainees of welding schools to unlearn some of the practices they have learned prior to going to work in a certain organization. Other differences usually lie in the organization of the work within the plant, its equipment, welding control, and specific shop practice.

The division of work in one organization differs from that of another so that some operators set up and weld structures, others simply set them up; in other organizations, welders do nothing but weld, and yet others have a sequence of upward progression from tack welding to other degrees of skill.

Some organizations have a close control of welding engineering by means of symbols on the blueprints; others expect their operators to get their information by a work sheet; and still others expect the welding operator to know by other means of control the procedures necessary for the job. Some organizations that make units of one kind have fixtures for the positioning of weldings, others do not.

The large organizations that manufacture complex units by the arc-welding method probably have the greatest variety of jobs; but they also probably have greater specialization of processes and fixtures, as may be illustrated by the work done in Fig. 149, which shows a specialized fixture for a portion of a large earth-moving unit bottom structure, which is produced by a team of two specially trained arc-welding operators who both set up and weld the unit. All the work on this unit is done according to a carefully controlled blueprint-conveyed system of welding symbols and procedure check sheets.

Arc-welding Job Analysis Required Prior to Training.—Because of this diversity of work and the fact that special training

is required for each individual prior to his taking his place in an organization's work, a careful program of arc-welding job analysis for each organization should precede the hiring and training of welding operators.

The manual dexterity and skill required to strike an arc and hold it for a sufficient length of time and with sufficient degree

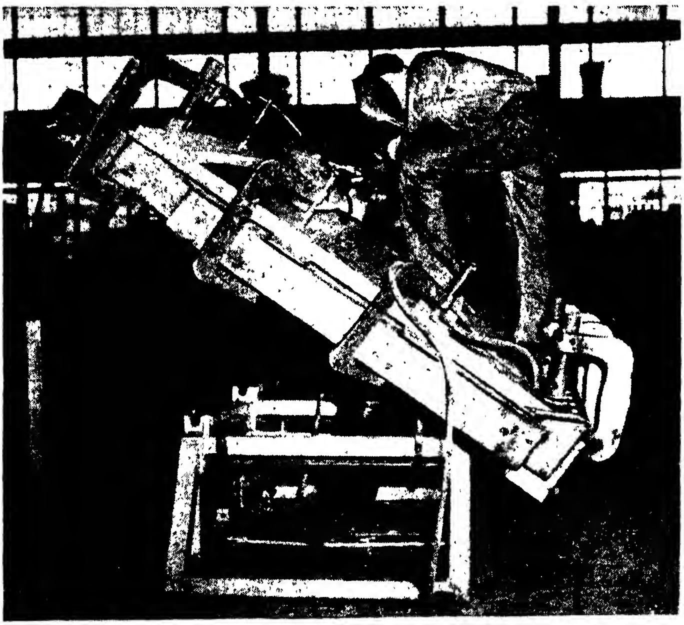


FIG. 149.—The special setups, sequences, controlled procedures, and teamwork of these two welding operators require training. (*Courtesy of R. G. LeTourneau, Inc.*)

of control to deposit a small amount of weld metal is about the only thing common to all manual arc-welding jobs. From there on, the specific nature of a job varies from one operation to another or from one shop to the next.

In some instances, the first job that a welding operator has is to strike an arc and maintain it long enough to deposit a small wart of metal called a "tack weld." From this, he may gradually develop the skill of depositing a small amount of metal to fill up gaps and holes and put in "drag beads," and there his job may end.

A slightly more complex welding job, yet one that is really simple, is the type of operation performed in some automotive

industries where all that is required of the welding operator is to be able to strike an arc with a given size electrode on a regularly occurring piece on an assembly line where the pieces are always the same, always presented to him in the same position, and where only a short weld of a specific form, size, and length has to

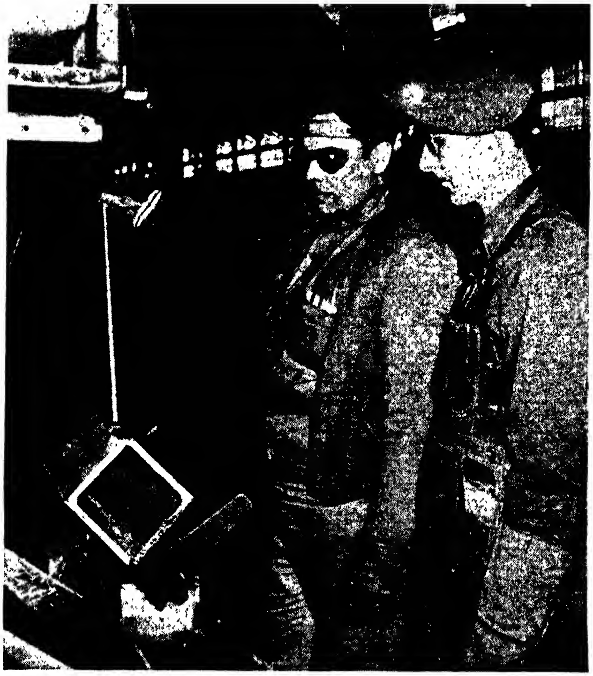


FIG. 150.—A full-time job of welding the box sections shown on this mechanized conveyor offers some variety because of changes in size of beams that result in changes in machine settings, size of electrodes, speed of travel, and size of weld. This is a good "first" job after the trainee leaves the training center. (*Courtesy of R. G. LeTourneau, Inc.*)

be deposited. The training for such a job is much simpler than the training required for a job such as that shown in Fig. 150.

The operator in Fig. 150 welds these box sections in only one position (always in the down-hand position), depositing the weld metal in a full open-corner joint as the box section which has already been set up and cut to length passes before him at a uniform rate of speed on the mechanical conveyor chain.

This job is more complex than the simple automotive welding job described in the foregoing paragraph because there is variety

in the size of these beams that requires a regulation of the speed of the travel of the conveyor, a difference in the size of the electrodes, and a difference in the adjustment of the welding machine; it also requires the tying in of the deposited metal at the end of each electrode when the next electrode is started to

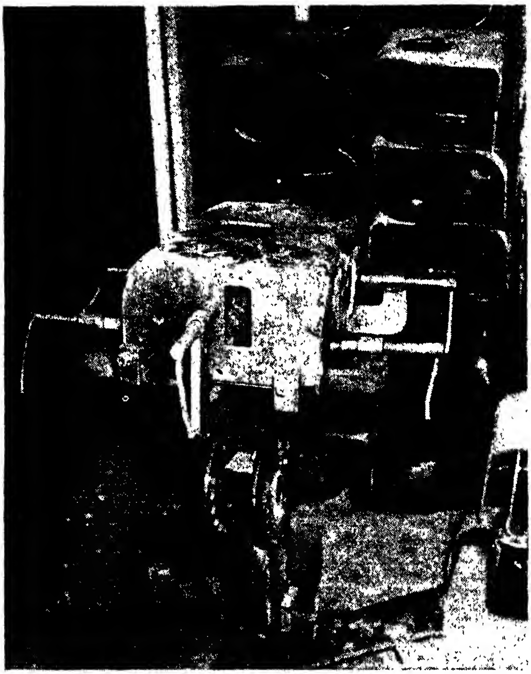


FIG. 151.—Another forward step in complexity of a welding operator's job in a production shop may be illustrated by the simple setup and positioning fixture for the production of this structure. Here he learns setup, fit-up, some variety of position in welding, and fixture operation. (*Courtesy of R. G. LeTourneau, Inc.*)

continue the weld toward the end of beam. The training for this job is naturally more complex than the training for the former job.

Another degree of complexity of work in the organization that produces these box sections is the step where the welding operator sets up simple parts, using a simple fixture, and welds them himself. This brings about a variety of welding and of positions of welding, requiring adjusting fit-up, some tack welding and also

a knowledge of the use of a simple fixture. Such an operation is shown in Fig. 151, where a formed plate has been cut to size and is placed in the fixture, after which the two end plates are placed in the fixture and tacked, and then the structure is welded.

A still more complex job is encountered when more intricate structures such as the one shown in Fig. 149 are set up and welded by one or two operators. This requires the ability to weld in different positions, including down-hand, horizontal fillet, some horizontal, and occasionally vertical welds.

Still greater steps of complexity are encountered when structures must be set up from the blueprints and welded without the use of fixtures. This usually requires considerable knowledge of setting-up practice, a considerable degree of mechanical skill in measuring, some knowledge of a sequence of operations to minimize distortion, and the ability to deposit weld in any position encountered in the manufacturing of a complex unit.

Still more specialized, although perhaps in a different way, is the type of welding that requires 100 per cent X-ray welding such as is encountered in pressure-vessel work or in piping which requires the ability to weld in difficult positions specified by special code tests.

With this variety of jobs as a background, it is well to keep in mind prior to the employing of either a trained arc-welding operator or one who has never welded that the job he is going to do or the progression of his training from jobs of less complexity to those of greater complexity should be carefully analyzed so that the best use may be made of the man's talent.

Training of arc welders is an expensive process and should be made as simple as possible for the beginner and as short as possible for the already trained welding operator in order to best fit him to the work that must be done in the shop.

Selection of Welding Operators or Trainees.—With the complete analysis of the job that must be filled in mind, the problem of selecting either a trained welding operator, who may be adapted by a small amount of training to the job, or of a trainee for welding is much simplified. This selection naturally follows certain of the regular personnel selective practices.

Normal attention should be given to the physical examination to determine that the applicant is in normally good health and

has the physical aptitudes of an average workman as defined by the requirements of the job.

It should be noted, however, that there are certain handicaps common among workingmen that do not affect their ability to weld. An applicant who has lost a foot or who has a defective leg may often be a good welding operator if the jobs that he will work on do not require heavy lifting, climbing, or other activities that would put him at a disadvantage. The limited use of one hand also falls in the same category. The loss of fingers does not usually interfere with welding dexterity.

Special attention should be given to the examination of the applicant's lungs; for, while few more welding operators suffer from lung ailments than do any other group of skilled craftsmen, there might be some cases where the normal amount of welding fumes inhaled would aggravate unnecessarily an already existing condition.

The applicant's eyesight should be reasonably good, although his hearing need not be 100 per cent perfect.

Special attention should be given to examination for hernias, if the job analysis indicates that the man will do heavy lifting or setting-up work.

From the psychological standpoint, it is well to remember that the arc-welding operator producing on a mass-production basis, or the operator whose main job is the deposition of metal, is a solitary worker. If the personnel department's practice is to give mechanical aptitude tests, it has been demonstrated (in some organizations at least) that the mechanical aptitude for arc welding on a strictly routine basis may be less than might be expected of a highly trained machinist.

It is not uncommon for organizations to train a completely untrained workman with no previous welding experience, rather than to train someone who has had some previous welding experience in an unrelated job, and who would have to unlearn certain procedures that he has been accustomed to doing.

In the selection of welding operators who have already worked at welding-production jobs, the wide variety of welding practice and welding jobs should be kept in mind by the personnel interviewer in order to do justice to both the man and the employer.

In the selection of already trained and experienced welding operators, there should also be a qualification test of some sort

that will measure the skill and ability of the applicant to meet the requirements of the particular job for which he is being considered. If these applicants, after the interview in the personnel department, can be allowed to take a qualification test, wherein they can demonstrate their skill and ability to the welding supervisor or some other qualified observer within the organization who knows the job for which they are being considered, there is much less likelihood of disappointment either on the man's part or on that of the employer. Many mistakes such as the man's being hired and found to be unable to do the work can be eliminated by a simple qualification test.

Qualification Tests for Arc Welders.—The qualification test for any arc-welding operator should be based upon the analysis of the job he is to perform and should contain in it the elemental things he must know so that it may demonstrate conclusively whether or not he can perform those operations. This does not necessarily require a complicated test. On the contrary, often it can be quite simple. The equipment required for a standardized test, or a series of standardized tests, may be made inexpensively and effectively in an ordinary welding establishment.

Figure 152 illustrates a fixture wherein a standard T type joint made of two standard pieces of steel and clamped into a fixture in such a way as always to present the same position and the same type of joint to the man who is being qualified.

Since this simple fixture is mounted on a revolving base on a perpendicular stanchion it can be raised or lowered and rotated so that tests in the down-hand, horizontal-fillet, vertical, or overhead position may be given, each according to the standard procedure that has been established to test the different classes of operators in a given manufacturing organization.

Such a fixture may be used to test men trained within the organization at the time of upgrading or for classification purposes; or it may be used for the classification of welding operators seeking employment in the company.

A part of the standard procedure for testing with this unit is to have the joints welded and then to take the welded sample and break it (either under a press or with a sledge hammer) and examine the inside of the weld. Such factors as surface appearance, undercut, overlap, correct dimensional size, uniformity of deposit, depth of fusion, amount of porosity, and freedom from

slag inclusions form the basis for the standardized interpretation of such a test.

For many specialized arc-welding jobs, there are well-organized and definitely prescribed qualification tests.

In the pipe-line-welding industry, there are standard means of making a test by welding a joint and cutting out standardized

FIG. 152.—This simple fixture provides the means for standardized qualification tests on a standard T joint held in any of four positions for welding, down hand, horizontal fillet, vertical, or overhead. (*Courtesy of R. G. LeTourneau, Inc.*)

specimens, bending some of them through the throat of the weld, and pulling others until they break either the weld metal or the pipe metal.

Such tests also are established for the airplane-welding industry where certain sample joints are made and analyzed.

Still further specialized tests are sometimes prescribed for the qualification of operators, especially in work that involves large public investment or the safety of the lives of large numbers of people. To ensure public safety in such cases, certain codes

are specified by such organizations as the American Petroleum Institute–American Society for Mechanical Engineers, one example of which is their "Unfired Pressure Vessel Code for Petroleum Liquids and Gases."

There are also standardized methods or codes for determining quality of weld metal prescribed by the Navy, the Maritime Commission, the American Welding Society, and other agencies.

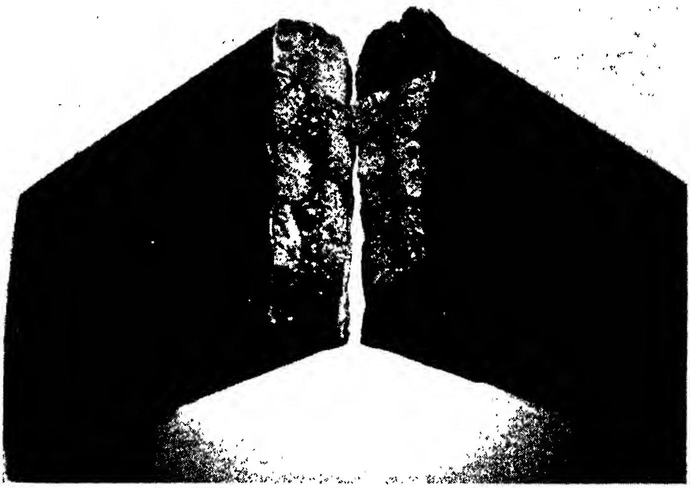


FIG. 153.—The nick-break test, specimens of which are shown, is a means of quickly and inexpensively testing butt joints, since the grain structure, freedom from defects, and amount of plastic flow indicate the quality and ductility with satisfactory completeness and accuracy for many welded structures.

The type of test often required for the thick materials is expensive and requires considerable time, money, and equipment to complete and interpret. Some tests require specimens of all weld metal to be machined from deep groove welds and to be examined by pulling, nick breaking, and checking their density. These tests are necessary to qualify materials and procedures for many welds and are, therefore, specified by certain codes.

The guided-bend test is less expensive, and in many cases seems to be a successful and satisfactory means of testing welded joints in thicknesses of material and types of joint where the bend test is applicable.

A method that is becoming more and more commonly used, both in manufacturing and in field-erection operations, is the simple nick-break test, specimens of which are shown in Fig. 153.

The sample weld is simply sawed into from each side, either vertically or crosswise, so that when it is bent and broken it will break through the weld. This gives the person who is interpreting the sample an opportunity to see how clean it is and to see by the plastic flow and the grain structure whether it is ductile or brittle.

All classification tests should be given consistently from test to test and from operator to operator and should, so far as possible, be interpreted by completely objective methods in order to get the fair results from their use. These tests do not necessarily need to be complex, but they should be consistent and carefully put together and analyzed to test the qualities of skill and craftsmanship required by the job for which they are given.

Introducing Trainees to Welding Training Preliminary to Metal Deposition.—This chapter is not intended to be a training manual for welding operators since there are several good ones available. The successive steps through which a welding operator should be taken will be outlined rapidly without the specific technique for introducing the operator and training him in the subject.

While there are many means of giving welding trainees the information and practice required to bring them up to the operator level of skill, the actual steps required are usually about the same.

In some types of work and in some organizations, the man who would learn to be a welding operator may sometimes start as a tack welder or may be otherwise associated with welding work and, on his own time, may be able to borrow a helmet and a lead and practice welding on scrap steel. This is usually a hit-or-miss training program in which the man learns by himself and under the shared experience of other welders on the job, but it effectively produces operators on some types of job where there is no formal training program.

For larger organizations, or for organizations that use a carefully controlled welding procedure, a specific and well-organized means of training is almost required. This may be in a separate school away from the shop-production lines, or it may be on the factory floor and be designated as a welding school.

Experience has shown that if such schools are organized so that every trainee has a machine and a lead and may spend his

time actually welding for several hours a day his training period will be much shortened. Arc welding is a craft that is closely associated with manual skill and must be learned by doing, not by observing.

When a welding trainee is introduced for the first time to the welding school, there are certain general facts that should carefully be considered, before he ever sits down in a welding booth to strike an arc. The first of these is the safety aspect of an arc welder's operation.

Since the arc gives off an intense light and heat, it is necessary to protect the eyes with special safety glasses and the face with a metal hood. The trainee should have the effect of an arc and its ability to burn the skin and eyes by direct rays explained to him.

The possibility of burns from molten metal splashing from the crater should also be explained, and the welding trainee should be instructed to get first aid, or properly take care of these small burns, since they can easily cause infections that are painful and even dangerous.

Safety shoes should be worn at all times because the welding operator's work frequently involves the use of heavy parts, heavy material, or fixtures that might endanger his feet if they are dropped or slip to the floor.

The general vocabulary of the pieces of equipment that the welding operator trainee must use should be explained to him at the start, prior to his actual learning to deposit metal. The type of machine, its adjustment, and the names of the parts with which the operator must have contact should be described to the learner (see Fig. 154).

The arc, the lead, the physical layout of the booth, and the way in which the current flows from the machine through the work to the ground, or vice versa, should be described to him as one of the fundamentals of his job.

The handling of weldings after they have been welded, with special emphasis on the fact that they are hot and also special instructions on the right and wrong way to lift them, should be pointed out to the learning operator.

It is also found to be good psychology when starting to teach a man to weld to familiarize him with all the equipment that he is going to use and to put him at his ease as much as possible

and also let him know that the operation he is beginning is not a dangerous or particularly difficult one, but one that requires time and patience so that proper coordination between hand and eye may be developed. After these preliminaries, the actual job of learning to deposit metal may begin.

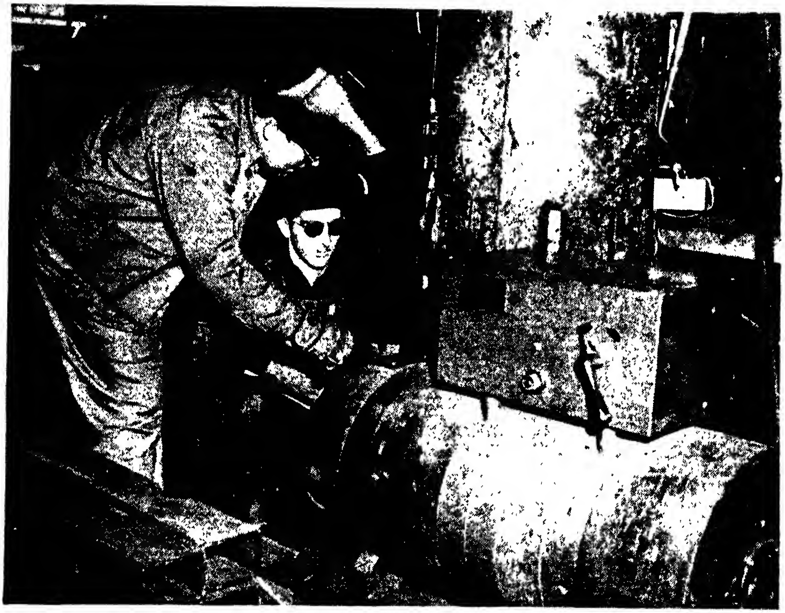


FIG. 154.—The student welding operator should have the machine—its parts, controls, and adjustments—carefully explained to him before he begins to weld, if he is to be expected to start, stop, or adjust his own machine. (*Courtesy of R. G. LeTourneau, Inc.*)

Instruction in Weld-metal Deposition.—From the beginning of the training of a welding operator, the type of job upon which he is first to work should be kept in mind.

The size of electrode, the type of machine, the type of metal upon which he welds, all are largely prescribed by the type of work that he will do. He should not be taught any more during his first welding training than is required for his first job, if a regular progression to more complex jobs or training for such jobs is provided after he has been on his first job for some time. He should learn to weld with the size of electrode and type of machine that he will operate on his first job insofar as possible.

The first step in learning to deposit metal is that of striking the arc. After this, the next important point for the student is that of maintaining the arc in such way as to keep it burning and depositing metal. Ordinary flat plate is normally as good a material to weld on as any other, and as soon as the welding operator has learned to hold the arc and maintain it, he should learn something about controlling the direction in which he travels and the width and size of the bead he deposits.

Following this, he should learn to stop an electrode and to start the weld again in the crater of the old one so that he can get a good tie-in and should master the technique of completing a smooth weld where a break must occur in the middle of it, if this kind of work is going to be included in his first job. It usually is so included, except in the simplest routine mass-production welding jobs.

After learning to lay a straight bead of a certain size, the trainee should be taught to weave the electrode in order to deposit a flat wide bead and so learn more about the actual controlling of the metal itself by manipulation of the arc. This is an important step because it leads to an important consideration in the next phase of his learning.

Down-hand Position Welding.—The first actual joining of metal a trainee should do, for most welding-training programs, is that of a down-hand position weld in either the fillet or the butt type of joint.

This can be accomplished by welding butt joints of pieces of metal together, or lap joints, T joints, or full open-corner joints where pieces are placed corner to corner and welded from the back or the front. The deposition of a weld of this kind is the first opportunity for the student to observe penetration and fusion and to give him a real objective in the welding which he does.

In this type of joint, he has the opportunity of building up the metal at the beginning of the weld and controlling the size of the weld, the problem of undercutting or overlapping is first encountered, and the problem of filling up the crater at the end must be met and mastered.

Beginning with the earliest beads that the welding trainee deposits on this type of joint, there should be frequent examinations of the inside of the welds he makes. This examination is

simple and can be accomplished by simply breaking the weld open with a sledge hammer as illustrated in Fig. 155. Such factors as overlap, undercut, slag inclusions, porosity, and poor penetration become realities in the mind of the student if he sees examples of them in his early welding experience.

The habits of workmanship that he acquires in the first few weeks in the welding school will have much to do with the kind of workman he becomes. For this reason, care should be taken

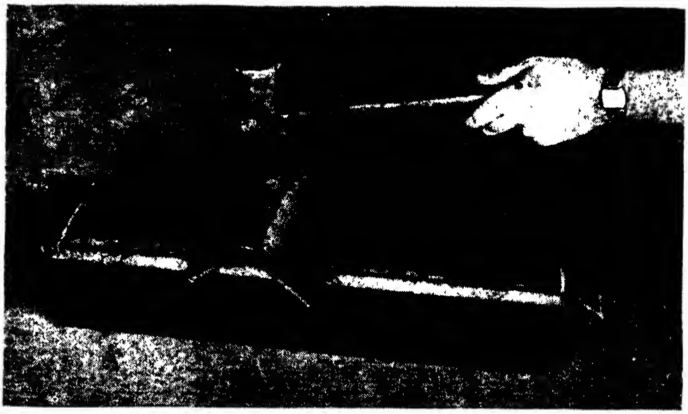


FIG. 155.—By breaking welds open as shown here, the penetration, fusion, porosity, and other features of quality may be examined and observed by the student and his instructor. (*Courtesy of R. G. LeTourneau, Inc.*)

to train him to burn electrodes down to the end, not to bend them, to treat them as a valuable tool, and to maintain clean housekeeping.

Horizontal Fillet Welds.—A welding trainee usually should not be trained beyond the time he has mastered the deposition of metal in the position in which he must do it on his first job, since the practice in weld-metal control that he gets on his first job leads to easier learning of the next steps and more economical use of his time and that of his employer.

In many production fixtures that allow for the down-hand positioning of most of the welds, there are occasionally one or two welds that must be made in the horizontal-fillet position. For this reason, and also because the horizontal-fillet-position weld is a fundamental step away from the down-hand position upon which almost all other more complicated position welding

is based, it often should be mastered before the trainee goes out on his first job.

The horizontal-fillet position differs from the complete down-hand position in that on all but the simplest of welds made in that position the welding operator must pay special attention to building up the metal on the vertical leg of the joint.

This building-up process, especially if it is done using a small electrode to make a large weld so that weaving must be done in order to obtain the proper size of weld, involves the fundamental learning that is necessary to "hang" the metal on an upright surface and then move the arc away from it quickly enough so that it will stay there.

This step is fundamentally the same as depositing a horizontal weld and as making a vertical weld from the bottom up wherein a small shelf of metal is hung on the side of the plates of a joint and then the weld itself is hung on the upright plates as the joint is welded to the top.

It is for this reason that great attention should be given to enabling the trainee to deposit a thoroughly sound and well-balanced horizontal-fillet weld with either the down-hand (American Welding Society E 6020 type electrode) or any type of electrode commonly used for all-position welding.

Many experienced instructors of arc-welding operators maintain that if a trainee learns to make a perfectly satisfactory horizontal-fillet weld with an all-position electrode which is half the size of the weld itself, he can easily learn all that is necessary for all the other positions of welding, since he has learned the fundamentals of handling metal in the mastering of horizontal-fillet welding technique.

Horizontal, Vertical, Overhead, and Special Welds.—Unless the welding trainee will have to deposit welds in these more advanced positions of welding, he should not be taught them prior to his spending some weeks or months on a simpler weld-depositing job. This is possible in many large welding organizations in which jobs are classified from the simplest to the most complex.

If a welding trainee may spend some time on one of the simple down-hand welding jobs where he deposits weld metal in the down-hand or in the horizontal-fillet position for a few months, he has learned the coordination of eye and hand, has learned to

tie in welds, and has gained much of the information that he will need for making satisfactorily sound and neat appearing vertical, overhead, horizontal, or other special welds.

His training then may proceed to the new positions of welding rapidly and in an orderly fashion in much the same way that his early training did; but now he will capitalize on the months of experience in handling metal that he has had on his first job.

In making any of the special-position welds, samples should be made and broken frequently so that the welding operator may be able to determine his own progress and check his own work.

Use of Flame-cutting and -heating Torch.—For organizations in which the welding operator does his own setting-up work, it is often convenient to train him in the fundamentals of the adjustment and use of flame-cutting or flame-heating torches.

In the setting up of complex machinery, it is not infrequently necessary for the setup man to do some heating and bending of certain parts of complex structures and possibly to trim off tack welds or reinforcements from structures when they have been put on for setup purposes.

In such cases, a little formal training in the care and adjustment of torches and tips and in the technique of using such equipment is a good investment. Since most of this equipment is made of brass or bronze and rubber, a reasonable amount of care should be exercised in its use. Also, since oxygen and some of the fuel gases that are used are relatively expensive, some study of the economy of using the proper pressures to get the best quality job is usually advisable. In many cases this type of training can be given in the school better than anywhere else. Normally, such training does not take more than a few hours (5 to 10 hr.) of class time and practice.

Transfer from Training to First Welding Job.—At the end of the training period that fits the trainee for his first welding job, he should be transferred to the job as soon as possible. His readiness for such a job may sometimes be defined by a qualification test, or it may simply be based on the instructor's opinion that the man can do the work satisfactorily.

At this stage of the welding operator's training, careful consideration should be given to the psychological aspect of the change that he is about to make.

He should be introduced to the foreman of his department, given instructions as to the various phases of his job the foreman must supervise, and given time cards, job cards, production records, etc.

Someone should then explain to him the job that he is going to perform. This man should be the foreman of the department if there is not a roving welding instructor in the organization.

The roving instructor who takes care of starting new men on their first jobs or old men on new jobs throughout the plant on all levels, independent of the foreman's supervisory duties, has been found by many organizations to be an especially helpful means of getting this kind of training done.

All the specifications regarding the job should be carefully explained to the new welding operator, and the instructor or foreman should stay with him until he has finished the first operation and has shown that he understands what is expected of him.

Any phases of control such as welding symbols on the blueprints should be explained and demonstrated to him if he has not already had the theoretical training that will allow him to read and properly interpret them.

The foreman or instructor should sympathetically work with him or watch his work until he has had the results of his first work inspected by the inspection department so that he will understand the function and decisions of the inspection department.

If there is an incentive system under which this man will be working, it should be carefully explained to him, as well as the factors that may or may not allow him to meet the standard time or production schedule.

Careful attention given to the trainee during these first hours on the job, and then a periodic check up to see how he is progressing, are important because they help to sell him on the job and give him self-confidence.

Progression to, and Training for, More Complex Jobs.—The welding-training center for many large welding organizations really amounts to portal training, because after the welding trainee has gone from it with the preliminary training required for his first job, the aid of roving instructors and the natural curiosity of the man who wants to prepare himself for better work allow him to train his eyes and hands and learn the fixtures and

practices of the shop sufficiently well to take the next more complicated job.

This type of learning is best fostered either by a system of roving instructors and procedure men who operate independently of the supervision of the shop, or by a progressive and careful

FIG. 156.—Even experienced operators should have special instruction on the new features of each new job. Here the instructor is explaining the details of controlling and operating a power-driven positioner to an experienced welding operator going on a new job. (*Courtesy of R. G. LeTourneau, Inc.*)

"training mindedness" on the part of the supervision which is passed down to the foremen of each department in the welding division. In either case, each man gets careful instructions covering the new features of his work when he goes from one job to the next.

The step that is being explained in Fig. 156 is simple enough and yet is new to the man who is going to a job on a power-

operated positioning jig for the first time. The careful explanation of the details of the control of the unit, the need for proper clamping of the parts, the proper precautions for guaranteeing the personal safety of the new operator, and the best procedure for doing satisfactory work help him to master the job with the least friction, loss of time, and motion.

Each successive step in complexity of job, whether it includes new setting-up and welding techniques, new fixtures and jigs, flame-cutting, or setting up without fixtures, requires the same type of personal instruction from a skilled operator.

The interpretation of operation sequence sheets and orders and the occasional analysis of the man's work from the standpoint of motion economy or other fine points of workmanship, if done constructively and with understanding, are definite parts of his training that contribute to his upgrading and certainly contribute to the over-all quality of his work.

Correlating Theory with Shop Practice.—There are certain supplementary fields of theoretical information that should go hand in hand with the training of an arc-welding operator.

Even though he may be doing the simplest type of setting-up and welding operations on small parts, he should be able to read blueprints. In the ever-increasing number of plants where welding symbols are being used, the operator should have a full knowledge of the symbols that occur on the blueprints or the other means of control used in that shop.

In addition to this, there are theoretical aspects to welding itself that many operators find interesting and that most find helpful in performing of their work.

Some of the things that an operator alone can control such as speed of travel of the arc, length of arc, angle of the electrode, and oscillation of the arc are well demonstrated in moving pictures which are available and which, if shown periodically, not once but several times, during the preliminary training of the new trainee help him to learn certain of the fundamentals.

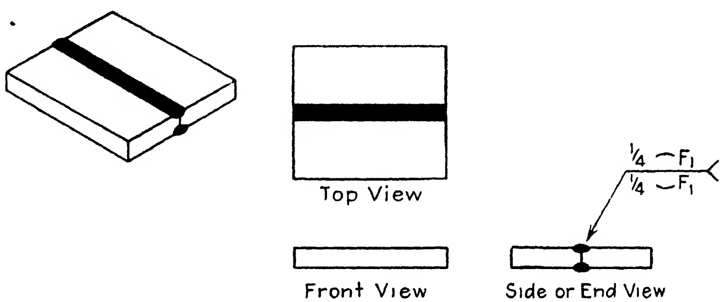
The question of what goes on in an arc, the reason for coatings on electrodes, what makes different electrodes different, the differences between alternating- and direct-current machines, and other such considerations frequently may profitably be studied from arc-welding instruction manuals of which there are several available.

This type of training may be given in the training center; it also lends itself nicely to training outside of hours in regular classroom classes or home-study courses for employees.

ARC WELDING AND WELDING SYMBOLS COURSE

Supplementary Sheet, Lesson 1

A FLAT BUTT-WELDED JOINT



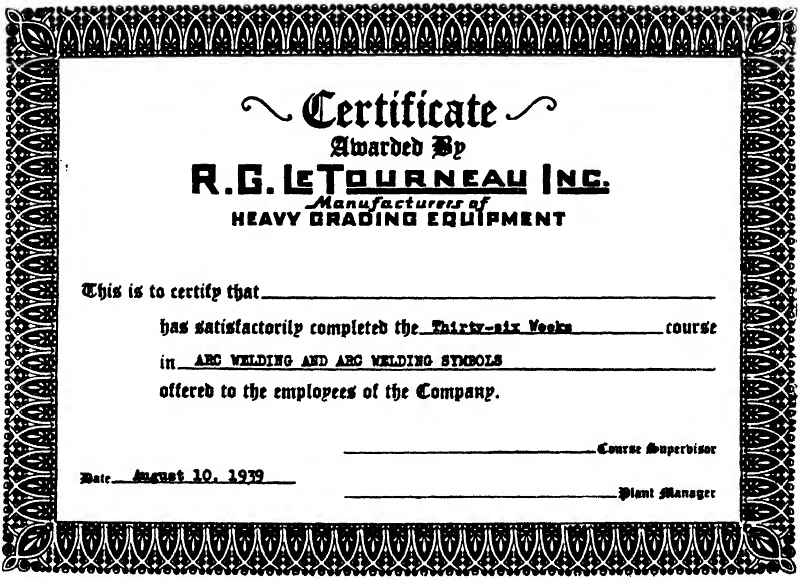
TWO PLATES, EDGES BUTTED TOGETHER, FUSED WITH A SINGLE FLAT BEAD ON EACH SIDE OF THE PLATE. THE WELDS SHOULD BE FUSED DEEP INTO THE PLATES. METAL PILED ABOVE THE SURFACE OF THE PLATES IS WASTED. THE WELD SHOULD BE SMOOTH AND UNIFORM IN WIDTH. THE SLAG SHOULD CLEAN OFF WITH VIGOROUS SCRAPING AFTER THE WELDED PLATES COOL. THERE SHOULD BE NO BUBBLES NOR HOLES IN THE SURFACE OF THE WELD.

THE ARROW AND SYMBOLS INDICATE THAT THERE IS A WELD ON EACH SIDE OF THE PLATE, THAT THE WELDS ARE OF 1/4" SIZE AND THAT THEY ARE WELDED AS FLAT BEADS IN ONE PASS.

FIG. 157.—This simple weld-symbol and blueprint lesson sheet is one of a series that one large welding organization presents to welding students during their first few days of welding school practice. It is a step toward necessary theoretical knowledge needed in that particular shop. (*Courtesy of R. G. LeTourneau, Inc.*)

Figure 157 shows one of the early "supplementary" lesson sheets that one company gives during the early training of a welding trainee so that he may begin to learn the fundamentals of blueprint reading (as he will see them on shop blueprints) and also how to recognize welding symbols as a means of giving directions for welding.

A series of such sheets is used in the welding training school and is followed later by a formal welding-theory class which presents the welding symbols and certain other fundamentals of welding in detail. At the end of this training period, if the trainee has satisfactorily completed it, the certificate shown in Fig. 158 is presented to him by the company as a mark of accomplishment.



Certificate

Awarded By

R.G. LeTourneau Inc.

Manufacturers of
HEAVY GRADING EQUIPMENT

This is to certify that ____________

has satisfactorily completed the Thirty-six Weeks course

in ARC WELDING AND ARC WELDING SYMBOLS

offered to the employees of the Company.

____________ Course Supervisor

Date August 10, 1939

____________ Plant Manager

FIG. 158.—Certificates of accomplishment, granted upon completion of courses in blueprint reading, shop mathematics, welding, and welding symbols, help to define qualifications and supplementary educational achievements in specific welding organizations. (*Courtesy of R. G. LeTourneau, Inc.*)

Further study in such subjects as flame-cutting, shop mathematics, and blueprint reading, may be sought by welding operators who are looking to the future and to bigger jobs. It is distinctly to the advantage of the management of large welding organizations to provide means for such training as home study or night-school class training.

Training to Adapt Already Trained Operators to New Types of Welding.—The training of experienced welding operators who are new to an organization so that they best fit into the plant's operations must be based upon a careful analysis of the procedures the welding operator knows that are similar to the job

upon which he will go as well as a careful evaluation of what he does not know.

With the wide diversity of types of welding performed in today's welding industry, a welding operator may be skilled and proficient at his work in one line of manufacture and yet have considerable difficulty in adapting himself to work in some other situation.

An example of such a situation might be visualized by considering the problems faced by the first-class welding operator

FIG. 159.—If a first-class aircraft welding operator, for example, were to be asked to weld this large structural-steel earth-moving machine part as it is normally welded, the job would be so specialized and so different from aircraft welding that the aircraft welding operator would require practice and training to do satisfactory work. (*Courtesy of R. G. LeTourneau, Inc.*)

from an aircraft plant making light motor hangars or airplane-fuselage frames and being immediately placed on the job illustrated in Fig. 159, which shows the welding of one large substructure of a heavy earth-moving unit.

The differences that the welding operator from the aircraft plant would observe would be many. In the first place, he probably would use a direct-current machine for the aircraft welding. In making this particular earth-moving unit, only alternating current is used. The size of the electrodes for the aircraft welding would be small. Those used in Fig. 159 are almost always $\frac{5}{16}$ in. in diameter and 18 in. long with currents

running as high as 550 amp. on some parts of the job. Obviously, the aircraft welding operator would have to learn, by actual manual practice, the skill and craftsmanship that would be required to perform the job on the larger piece of heavy equipment. In the same way, the operator who is doing the work shown in Fig. 159 would have at least an equally difficult job to learn to be a first-class aircraft welder.

It is because of differences of this kind among branches of the arc-welding industry that a careful qualification test or analysis of all the qualifications of arc-welding operators applying for work in a welding organization must be given. When they have been properly analyzed, it may be that the work is nearly enough alike so that the operator may learn the necessary new steps on the job much as if he were graduating from a simpler to a more complex job within the shop.

On the other hand, the differences may be great enough in some cases so that it would not do justice to either the operator or the organization to try to put the man on the job without preliminary training.

This preliminary training, in large organizations, may often be done as well in the training center as anywhere else, since the skill that the learner must obtain is primarily the same as that which a new welding operator must master after he has learned to hold an arc and to control weld metal in depositing a simple weld.

CHAPTER XIII

ARC-WELDED SHOP FIXTURES AND ACCESSORY PRODUCTION EQUIPMENT

One important item of expense in any manufacturing layout is the large and varied group of special accessory equipment that makes up the furnishings of the plant, aside from the standardized machinery and processing equipment.

An increasing number of manufacturers of arc-welded goods are following the practice of making many of their own shop fixtures by arc welding as the quickest, most economical, and most effective means of producing the special fixtures needed for their jobs.

These fixtures include such things as the racks and equipment used for the storage of parts or raw material (Fig. 160); the buggies, monorails, tote bins, skids, carts, or conveyors that are used for the handling or transportation of parts; the specialized jigs and fixtures used for the processing or production of the salable products of the plant; the special modifications made to adapt standard machine tools, motors, hoists, and other standardized factory equipment to the specific production of that organization; and even, at times, the manufacture of specialized machines for large-volume mass production.

Most of these accessories to production equipment are, of necessity, specific to the organization; but however they are made or acquired, they usually make up a significant portion of the business operating expense called overhead.

Since the arc-welded method of production of many major products in modern industry has been widely accepted and since many large organizations are producing quantities of welded goods, certain inherent advantages in the use of the arc-welded method for manufacturing these special accessories to production and shop furnishings represent an important economic factor in today's manufacturing costs.

The organization that has the equipment and the trained personnel commonly used for the production of arc-welded

products already has within itself the necessary tools and elements for economical production of many items of shop equipment that may be built specifically to meet its particular need.

Special Advantages of Arc Welding Shop Fixtures and Accessories.—A modern, reasonably skilled maintenance welding operator today can produce in steel the same kinds of fixtures and equipment that would be produced in wood by a skilled millwright, carpenter, or cabinetmaker.

FIG. 160.—This 11 ft. high, 28 ft. long, and 24 ft. wide all-welded steel storage rack can store large quantities of steel in an area not much larger than the volume of the steel itself. Overhead crane loading and unloading is possible because of its simple design. (*Courtesy of R. G. LeTourneau, Inc.*)

The arc-welded method of production is peculiarly adapted to the production of fixtures because of the fact that a large variety of shapes, sizes, thicknesses, and forms of commercial steel (as rolled and received from the mill) may be cut, stamped, shaped, premachined, and placed together in such a way as to form the functional parts of the fixture, whether it be a conveying unit, a motor bracket, a machine base, or a transportation buggy; and the fixture may be fused by welding, so that the joints are as strong as the parent metal and usually so rigid that special lap plates, or heavy bracing, need not be incorporated into the design.

Such structures are usually characterized by great strength and ruggedness and by an ability to absorb the type of abuse and extremes of service that are common in the handling of the steel parts found in the factories of manufacturers of welded equipment.

Since one of the important factors in the manufacturing of arc-welded products is the efficient use of material and since in almost any arc-welded operation there are end cuts of bar stock or segments of plates left over after the salable product of the organization has been cut from them, it is frequently possible for many of the shop fixtures to be built from material that is a by-product of the shop's major production items and that would otherwise be sold for scrap.

In a plant that manufactures welded products, there are already welding machines, flame-cutting outfits, bending and forging machines, and machining tools that may be used to produce most of the simple shop fixtures with comparative ease. This is especially true if the organization does any experimental and developmental work on its own product or if it has a reasonably well-organized maintenance organization for rebuilding, maintaining, and servicing its regular production equipment.

Another asset that lends itself readily to the making of shop fixtures is the group of skilled operators, mechanics, and workmen available in different departments of the organization, such as the engineering department, the jig-and-fixture department, and the tool-and-die department.

This group of skilled workmen is an extremely important asset in the manufacture of shop fixtures because one of the most important and greatest potential sources of economy in industry is the ingenuity of such workmen.

It is the maintenance foreman, the experimental-department mechanic, the operator who is working on a process involving a jig or a fixture and offers a suggestion for its improvement, and other such workmen who are closely related to the actual work of the factory who can see most clearly the specific need for fixtures and production accessories. The jig and toolroom clerk can see the need for such a rack as shown in Fig. 161 because in order to serve the shop adequately an orderly means of storage is necessary.

If this great potential source of ideas and energy can be allowed to express itself within the organization so that the correct jigs and fixtures, handling equipment, and other accessories that

relate themselves specifically to the needs of that factory may be made inexpensively and effectively, it not only provides a cheaper method of producing such fixtures, but it also adds a considerable incentive to the workmen within the organization because they can see their own ideas related to the needs of the plant expressed in a form of specific answers to their problems.

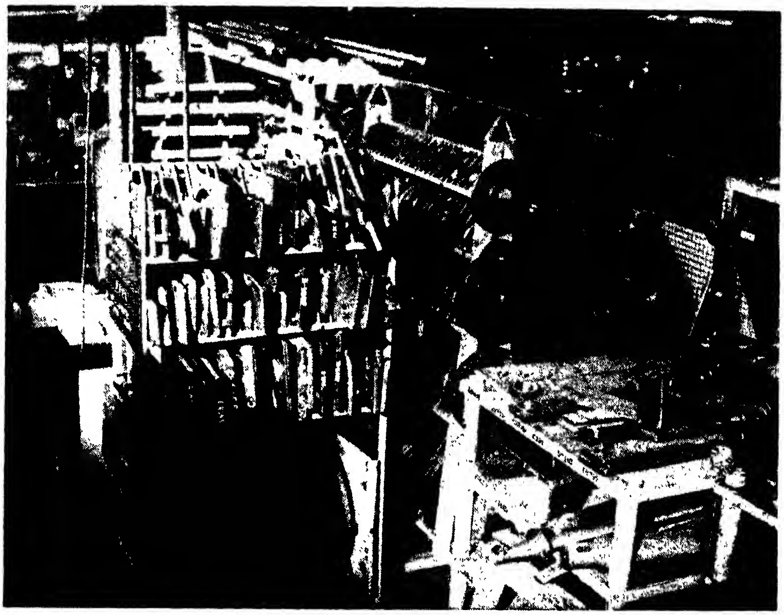


FIG. 161.—The jig and tool room foreman and clerk could best see the need for these jig and tool racks. They visualized and sketched the design, and the racks were fabricated by arc welding from available materials. (*Courtesy of R. G. LeTourneau, Inc.*)

Since the equipment and materials are already on the premises and a part of the capital investment or regular inventory, the skilled labor is available, and the ingenuity of the organization is willing, the fixtures and accessories necessary in the factory may be made without having to be further adapted, as standardized equipment such as might be purchased to meet the specialized requirements of that organization. They are thus acquired without some of the costs that are natural factors in selling prices of standardized equipment, such as sales expense, profit to the manufacturer, and other special service charges.

Another advantage of the arc-welded method in the production of such equipment is the element of time. When the need arises for fixtures or accessories, after the appropriate amount of study has been made to determine the type of fixtures that might best serve the purpose of the organization, the mechanics for getting the material together, processing it, fabricating it, and getting it into operation as quickly as the situation demands depends only upon the speed of the organization's own fabricating and processing. This is often an important factor, since for certain fixtures that are commonly necessary in factories, it might require days, weeks, or even months for an outside organization to engineer the plant's requirements, design and order them for production, get the materials, process them, finish them, and transport them to the factory in which they are needed.

Still another feature of manufacture of such equipment within the plant is that there are usually certain standards of appearance required by the commercial manufacturers which call for the expenditure of time, workmanship, and materials and which may not necessarily be essential in the function of the fixtures; whereas if those fixtures are built within the plant, the function and not the appearance is the major consideration and, therefore, additional expense may be saved.

In the following paragraphs, examples of classes of accessory furnishings that have been manufactured within one large arc-welding earth-moving machinery manufacturer's organization (R. G. LeTourneau, Inc., Peoria, Ill.) will be described as examples of how the use of arc welding for the manufacture of such equipment may be made to serve the economic and practical needs of the organization. These individual applications represent only classes of shop accessories or fixtures used in that particular organization.

Material Storage Racks.—The steel racks shown in Fig. 160 are made up of 4- by 4- by ¼-in. box sections made of two angles welded together. They are 11 ft. high, 28 ft. long, and over 24 ft. wide.

By removing the 1¼-in. square crosspieces, which are inserted into holes in the side of the upright section, this rack may be entirely loaded by an overhead crane; or, if sufficient stock is to be removed at one time, it may also be unloaded the same way.

Note the skeletonlike structure of the rack, free of braces and encumbering features of design, and yet capable of elastically handling large quantities of heavy materials within a space that is little larger than the cubic content of the materials being stored.

This rack is only one of a large variety of similar racks that find their appropriate place in the storage of other types of steel, rough bar stock, raw materials, and cut structural parts on the fabrication department floor and in other appropriate parts of the building. The simplicity with which such a rack may be constructed and the effectiveness of the service that is rendered make it an inexpensive but distinctly specific fixture that serves a necessary function in the plant.

Machine-shop Jigs and Fixtures Rack.—A common storage problem in flame-cutting departments or in machine-tool rooms is that of storage of production templates, dies, jigs, and fixtures in an orderly manner that is also economical with space.

The racks shown in Fig. 161 for the storage of drill jigs in the toolroom of a machine shop for machining arc-welded structures, and the adjacent rack for storage of more bulky fixtures, embody many of the almost ideal characteristics of such a storage rack.

Here again the relatively small structural volume of the steel that makes up the rack, coupled with its rigidity and strength and its use of space when fused by the arc-welded method, allows the items stored in the rack to be arranged in such a manner as to be available, yet not be wasteful of space because of bulky or cumbersome racks, nor to endanger failure because of structural weakness of the rack itself.

Storage Bins for Central Warehouses, Main-parts Rooms, or Small Parts on the Assembly Floor.—The problem of storing parts in the most readily accessible type of bin and yet in the smallest space required is a major consideration in the storage or warehousing of parts.

The all-welded steel bins shown in Fig. 162 represent a corner of a central warehouse for the storage of finished welded parts or assembly parts. They are composed of several standardized stock bins which, when placed together, form the walls of the storeroom as well as the means of storage of a large quantity of parts in a small area.

This particular rack is made in sections five compartments high by five compartments long, each compartment being capable of

holding approximately 2½ tons of solid parts. They are made of light-gauge metal, reinforced by somewhat heavier strips that form the lower lip of the storage compartment and also lend reinforcement to the structure itself.

Modifications of such an arc-welded bin using various sizes and various numbers of compartments answer a large variety of

FIG. 162.—One corner of a main storage room for steel parts. These simple bins of all-welded design from light-gauge metal form the walls of the storeroom and can store large quantities of parts (2½ tons of solid parts per single compartment). (*Courtesy of R. G. LeTourneau, Inc.*)

needs in the manufacturing and storage departments of this particular organization. They are simple to make, relatively inexpensive, and economical from the standpoint of space.

Arc-welded Shop Tote Bins and Hauling Equipment.—The problem of economically providing temporary storage or transportation facilities for a large variety of parts, especially in an organization that manufactures steel products, is one in which the arc-welding method of producing tote bins, transportation skids, and hauling buggies offers many real advantages.

Figure 163 illustrates a group of two standardized types of material hauling and temporary storage bins and skids manu-

factured by the arc-welded method that are effectively serving the needs for which they are made.

The bins and skids illustrated in Fig. 163 are capable of handling approximately 4,000 lb. of solid steel parts, although frequently the skids have less capacity because of the skeletonlike forms of many parts or the number of parts that are being handled per order. Note the tote bin, No. 125, in the center of Fig. 163,

FIG. 163.—These tote bins and skids were made within the plant on a mass-production basis to give elastic handling and temporary storage facilities. They are used with shop lift trucks and their rigid, rugged construction makes them most serviceable. (*Courtesy of R. G. LeTourneau, Inc.*)

which is constructed of 14-gauge material, reinforced with channels across the bottom under which the lift-truck forks may be thrust for lifting. There are channels around the top upon which there are loops by which the unit may be handled by the overhead crane, and box section legs which nest so that they may be piled as high as is convenient for the particular storage purposes they are serving.

Similarly, the skids are made of $\frac{3}{16}$-in. bottom plates with channel reinforcements about the side and standard-height legs with caps on the bottoms so that the skids may stack into piles. Such standardized skids and bins may be made with the available

equipment in the shop, in such numbers as may be required on a standardized basis, and may be adapted to the particular need of the shop.

For specialized handling of larger and more bulky parts, similar racks and bins of larger dimensions may be made equally effectively, again depending entirely on the need. This elasticity of the arc-welded method of construction enables almost any problem of this kind to be solved without undue expense and in a short time.

FIG. 164.—This simple, all-welded shop transportation buggy is light in weight, mobile in service, and capable of withstanding extremely heavy service in either hand-pulled service or power-lift truck hauling. (*Courtesy of R. G. LeTourneau, Inc.*)

In order to complete the elastic handling of equipment within the shop, a number of standard small hand buggies, such as the one shown in Fig. 164, were made using angles, pipes, small lengths of bar stock, and a section of plate for the bottom. Some of the parts were end cuts that normally would have been considered scrap. The simple three-wheel construction allows for mobility; the arc-welded construction gives rigidness, ruggedness, and relatively light weight so that the unit may be handled by hand. For heavy transportation, the buggy may be loaded with as much as two or three tons of stock and pulled either by hand or by a shop-lifting or hauling truck.

This buggy represents one of the standardized units for hauling within the shop, but at least three other types of arc-welded buggies of a larger size or specialized shape were made for certain specialized hauling jobs within certain departments, simply

because there was enough hauling to justify the making of a simple, specialized unit for such handling and because of the ease with which the unit could be made by arc welding.

Cranes and Overhead Handling Equipment.—Another major portion of the handling equipment of this large shop is a series

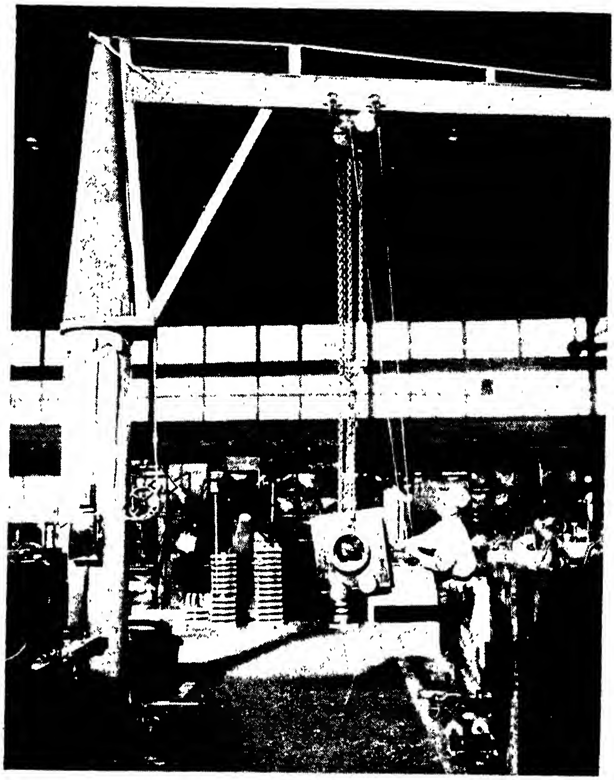


FIG. 165.—The 52 ft. diameter floor-service area and high lift of this $2\frac{1}{2}$-ton capacity arc-welded jib crane is a good example of how the rigid and structurally strong welded design allows efficient use of materials and space in solving hoisting and handling problems. (*Courtesy of R. G. LeTourneau, Inc.*)

of overhead cranes combined with stationary jib cranes that allow overhead service to all parts of the shop where heavy lifting must be done.

The arc-welded jib crane, shown in Fig. 165, is an example of arc-welded construction for efficiency in handling of heavy materials. This crane has a lifting capacity of $2\frac{1}{2}$ tons and a 52-ft.-diameter floor-space service.

The overhead crane that passes over it clears it by only about 5 in., yet the boom construction of the crane itself plus the hoist occupies less than 3 ft., so that the maximum working space is available under the boom.

Jib cranes of arc-welded construction, with its rigidity and skeletonlike design, make possible this effective use of space, limiting the structural members of the crane itself to a small area that lies just below the overhead crane space clearance and yet giving maximum working height underneath.

The arc-welded construction of overhead cranes lends the same rigidity, ruggedness, structural strength, and economy in the use of space as is demonstrated by this crane; and, in this particular case, a 10-ton crane with a 96-ft. span is constructed within the depth of the I-beam main beam members so that the total clearance between the top of the jib crane, shown in Fig. 165, and the rafters is less than 5 ft.

A large variety of jib cranes, stationary beam cranes, and other overhead hoisting applications may easily be made to fit the need by the use of the arc-welded design. The same is true for the framework of overhead monorails and conveyors; for the problem resolves itself into forming the skeleton structural members of the required units in such a way as to support the functional hoists, rollers, rails, or points of contact and simply welding them together using the available equipment and stock from the shop.

Arc-welded Engine Bases and Motor Brackets.—A part of the first cost of a factory unit involving an engine or a power machine almost always involves some adaptation of that unit by means of a motor base or a mounting fixture so that the unit performs the specific function for which it is purchased.

The motor bases shown in Fig. 166 are examples of one of the infinite variety of methods of mounting motors or power units to serve a specific need. Arc welding of box sections and plates formed the major portion of the manufacture of these engine bases, which were built one or two at a time as they were required during the growth of this plant's power plant.

The large major box members at the bottom of the base were filled with concrete to lend weight to the base and stability to the motor-generator assembly, and the available shapes and structural members that were to be found in the shop were used to build them. Bolt blocks and bearing seats were cut from bar

stock and machined prior to being welded into these bases. They might equally well have been cut from I-beam sections, channel sections, H, Z, or T beams, if these had been standardized materials in the shop, available for such a base.

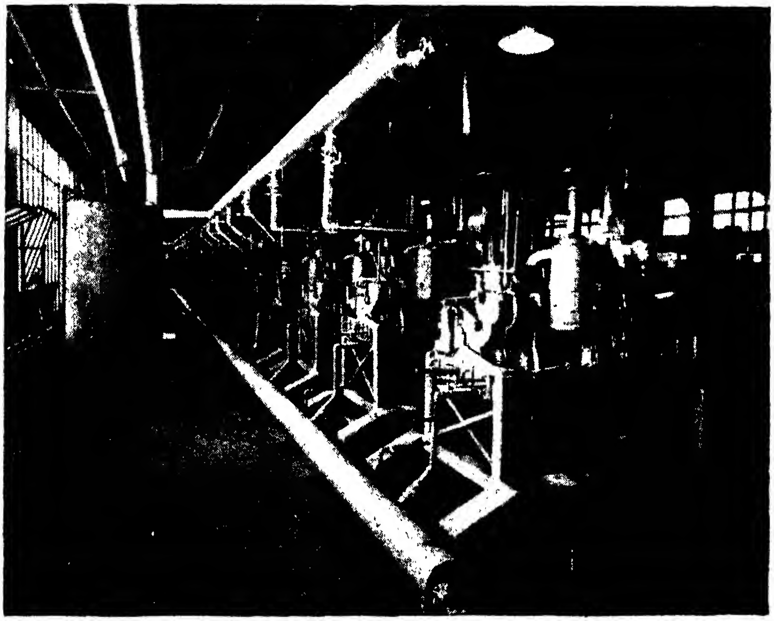


FIG. 166.—These all-welded motor bases illustrate how motors or power units may be adapted to their special application by fabricating a base from available steel and scrap stocks within the plant. (*Courtesy of R. G. LeTourneau, Inc.*)

A similar application on an electric motor is shown in Fig. 167, where the skeletonlike bracket has been produced to mount the main motor guard for an all-welded wire-rope closing machine.

This bracket again exemplifies the ease with which a skeletonlike framework may be bolted on a small footing on the framework of the machine itself, and by a simple means of laying out and cutting the structural members and welding them together, the "millwright work in steel" may be made to produce almost any kind of motor mounting (or base) required on almost any machine of steel construction. Here again, small premachined bolt blocks allow the base or bracket to be made without machining the entire structure after it has been welded.

Machine-tool Bases and Adaptors.—In the same way that motors and engines often must be mounted on specialized bases after they are received at the plant, it is frequently a source of considerable economy to place certain types of machine tools,

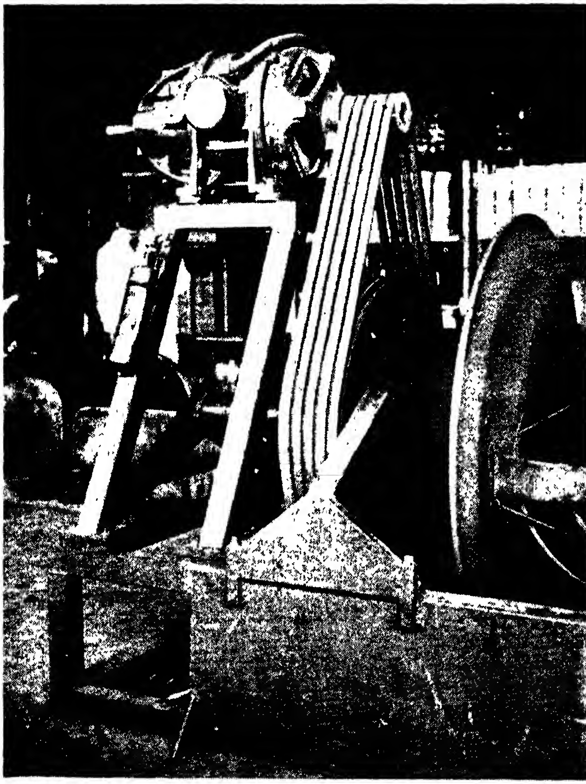


FIG. 167.—This electric motor mounting bracket was made on the job to fit the special need. Premachined bolt blocks and short lengths of scrap plate and box sections were quickly fused into a rigid and efficient mounting base. (*Courtesy of R. G. LeTourneau, Inc.*)

such as the radial drill shown in Fig. 168, on a specialized base in order to make more efficient use of them.

In this case, a simple steel base constructed of a relatively light bottom plate, a 1-in. top plate, spaced apart by boxlike side plates and center web plates (to keep the base from diaphragming), followed by the construction of a very light pan around the base for coolant and the mounting of a coolant pump gives this radial

drill a large base. This provides two drilling stations over specialized all-welded steel layout and hold-down plate structures, one of which may be used while the drilling operator is laying out work and preparing to use the other. This allows the drill to

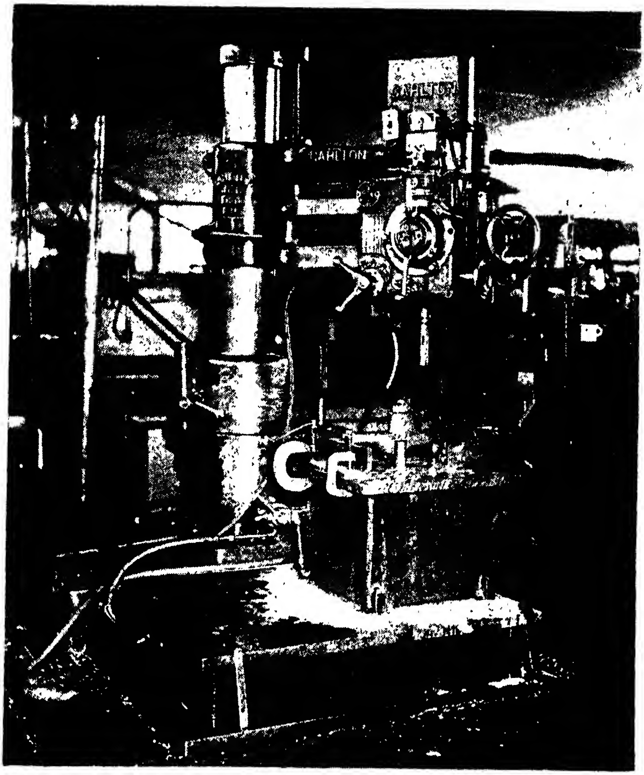


FIG. 168.—Specialized welded machine tool bases and work tables such as this one may be made economically and quickly within the plant where they are needed. They often increase the efficiency of the machine, as shown by this two-station base which almost doubles the output of this radial drill on some jobs. (*Courtesy of R. G. LeTourneau, Inc.*)

be used a larger percentage of the time than it could be if confined to a small single station bed and one operator.

The rigidity of the base itself, plus its machined surface, provides an accurate primary base from which to work and freedom from diaphragming and springing as heavy cuts are taken in the machining operation. It therefore results in more accurate work with closer tolerances than would be possible with a smaller, less rigid base.

The hold-down table mounted on top of the base is a relatively simple arc-welded structure containing an air vise which facilitates holding down parts quickly and positively.

The ease with which such bases and specialized hold-down tables may be made makes the production of such fixtures both

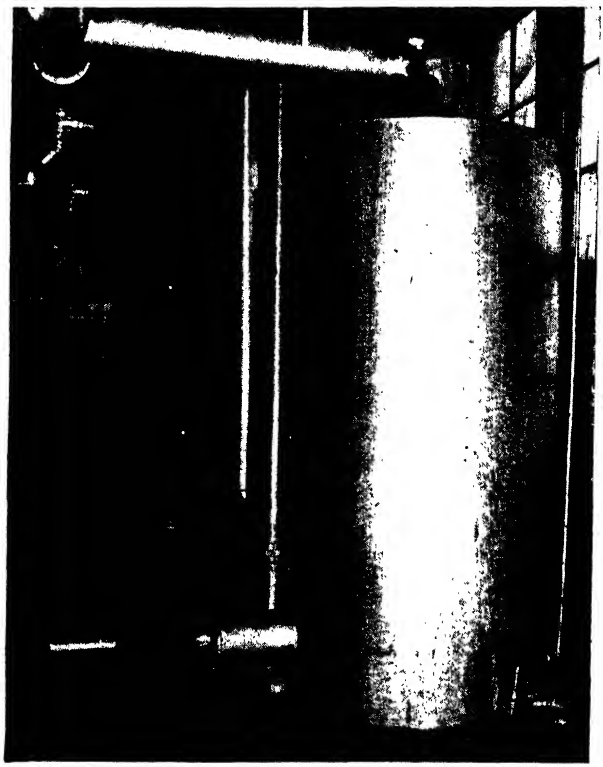


FIG. 169.—No two piping and liquid (or gas) storage and handling systems are exactly alike. A maintenance welding operator with a cutting torch, some material, an arc-welding machine, and a tank or piping problem can produce the needed system quickly and effectively. (*Courtesy of R. G. LeTourneau, Inc.*)

economical and efficient, for it renders the service of the machine specific to the need of the particular plant in which it is being used.

Storage and Handling of Liquid and Gas Commodities.—The effectiveness with which the arc-welded method of construction may be used to make storage tanks that are specifically adapted to the size and type of applications dictated by the needs of the plant is illustrated by the tank and piping system shown in

Fig. 169. This application is part of the cooling and circulating system for the motors in the power plant shown in Fig. 166.

The liquid- or gas-tightness of welded joints in this piping system renders it unsurpassed as a means of establishing such systems, yet offers the elasticity and simplicity of construction that puts it well within the reach of the average maintenance welding operator who is capable of simple layouts, flame-cutting parts to the layout, setting up the parts, and welding them together. Almost any shape of piping system may be made in order to clear structural members of buildings or to adapt the piping system to existing or specialized requirements of the situation, yet with a minimum of materials and expensive features. The elimination of the type of threaded sleeve joints and T's and elbows for the greater part of such a piping system (as shown in Fig. 169 or, from a different angle, in Fig. 166) is a valuable source of economy. The construction of tanks as shown in both figures is an economical means of handling the liquid- or gas-storage problems encountered in a modern shop producing steel or metal products.

Such tanks as fuel oil; gasoline; kerosene; quenching water, brine, or oil; water storage; butane and propane storage; or any of the almost endless variety of tanks for commodities may effectively and specifically be made to meet the industry's requirements by use of the equipment, materials, and workmen within the plant.

Arc-welded Furnaces and Heating Equipment.—Another example of the construction of specific shop equipment to fit a certain need is illustrated in Fig. 170, which shows an all-welded forging furnace constructed to the size, heat capacity, and other specialized features that are dictated by that particular job.

The structural body of the furnace itself was made of plates, box beams, channels, or I beams (whichever lent themselves best to the design or were available) which produced a relatively light but strong shell of the proper size and correct form to answer the needs of that particular furnace. After the shell was welded and the fixtures for actuating the doors by an air jam were placed on the frame, the unit was lined with refractories, connected to the fuel line and, after burning in, was ready for service. It is a specialized unit built simple, inexpensively, and with a minimum amount of time and inexpensive material to do a specific job.

This particular furnace is only one of over half a dozen different types of furnaces used in that organization, each of which is built for a special purpose. Standard furnaces could be purchased that would serve each of these functions, yet they would not be specific to the need; would represent a compromise as to form, size, space, or some other function; and would certainly cost considerably more than this furnace manufactured within the organization.

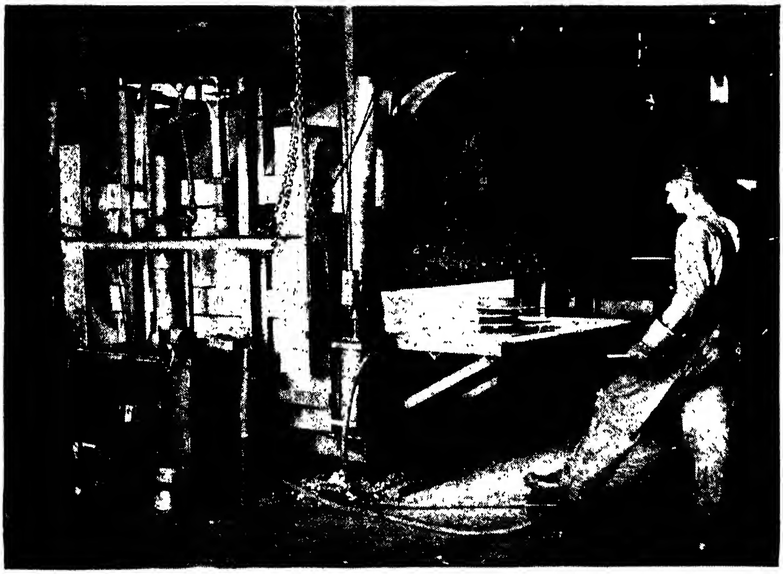


FIG. 170.—Forging and heat-treating shops often require a variety of furnaces for their specific work. Rigid, light, strong furnace shells and frames may be easily and quickly produced from ordinary shop steel stocks by arc welding within the plant where they are needed. (*Courtesy of R. G. LeTourneau, Inc.*)

Special Jigs, Fixtures, and Specialized Processing Machines by Arc Welding.—The examples of arc welding applied to shop fixtures in the foregoing paragraphs are representative of general groups of problems of which there is an almost unending series, depending upon the particular organization and its specialized needs.

It is almost standard practice for producers of arc-welded goods to make the setting-up and welding fixtures upon which their products are produced and frequently to make the dies, machining jigs, and specialized machining fixtures associated with the production of such units.

The same advantages that apply to the simpler jigs, fixtures, brackets, and other items that may easily be made in a plant may also apply to certain specialized processing machinery pro-

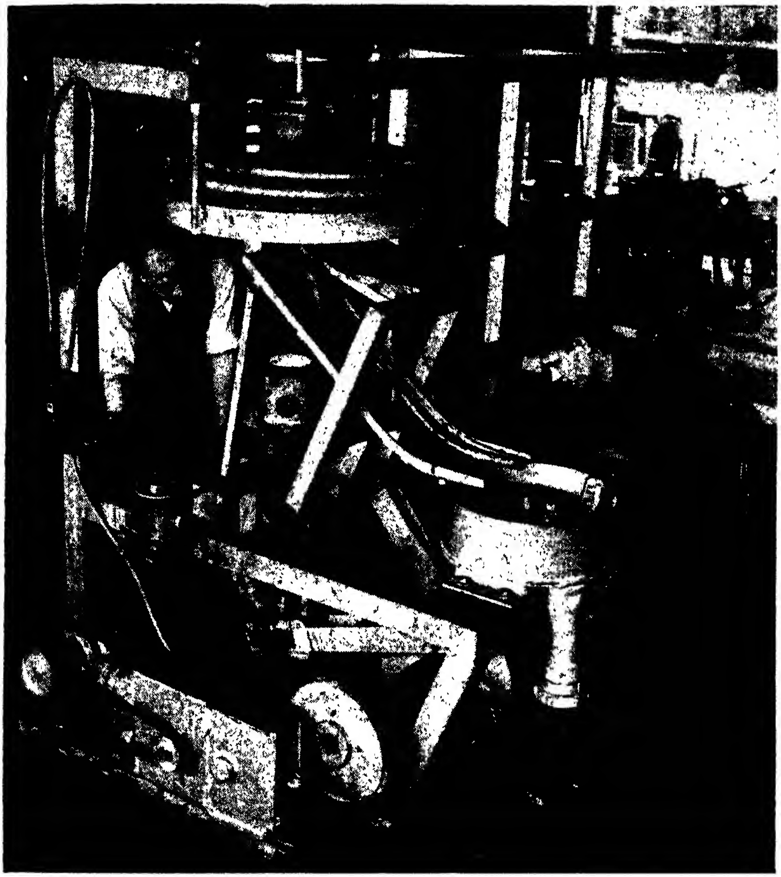


Fig. 171.—The design and construction of such specialized machines as this automatic sheave wheel hardening machine (in process of development) is a practical and economically sound outgrowth of practice in designing and welding simpler shop fixtures such as bins, skids, brackets, motor bases, and other simple equipment. *(Courtesy of R. G. LeTourneau, Inc.)*

duced by the arc-welded method, whenever there is a sufficient volume of some specialized process to be done that would be simplified by the production of a machine to do the job.

Such a machine is shown in Fig. 171 where a specialized heat-treating unit is in the process of manufacture. This unit, when

completed, will be a four-station automatic flame-hardening unit that heats and then transfers a sheave wheel to the quenching fixture and quenches it automatically with split-second control and accuracy.

At the stage of completion at which the picture was taken, only the first experimental station was in the final stages of construction prior to the duplication of it in the next three stages (to be seen in the background) and prior to the housing in of the gears and working parts so that the working parts would be protected from foreign materials and the workmen protected from the working parts of the machinery.

This specialized machine is made up of the simple materials that are the raw materials used by arc-welding artisans where the description of the functions that must be performed are translated into simple structural framework and functional parts, including such parts as the welded gear case, the fabricated herringbone gear, the cam-shaft arrangement, the liquid quenching system shown in the foreground, and the gas-heating device in the upper left-hand (coil shape) structure, all supported by the simple box-beam construction framework.

Limitations of "Home-made" Shop Equipment.—The extent to which such specialized machines may be built by an organization depends somewhat upon its experience in arc welding, yet they are a reasonable outgrowth of the experience gained in building motor bases, brackets, fixtures, jigs, racks, and other simpler units of factory accessory equipment.

A careful study must be made of the amount of work that must be done in order to justify the expense of designing and producing such specialized equipment, yet full account must be taken of the fundamental economy possible in the organization that is already using arc-welded construction. These include availability of materials, skilled workmen, processing (fabricating) equipment, and the fact that overhead is already being paid on such experimental departments and other departments that enter into the construction of such equipment. The fact that no sales cost or manufacturing profit need be charged to such specialized equipment when it is built in the plant specifically for some purpose within that plant and that "fancy" finishing may be eliminated, materially reducing the cost of such shop-made equipment, also must be considered.

By keeping careful records of the costs of building the simpler racks, fixtures, brackets, etc., that are used in the plant, an estimate of costs on labor and material for specialized machinery may be established. This may be used to demonstrate the available margin of economy for building a specialized unit for a specialized job in the plant, in comparison with paying the price for standardized equipment and adapting it or the constant compromise for less efficient operation compared with the possible efficiency to be gained by specialized machines. The arc-welded method of construction often presents an interesting margin of economy in favor of the production of the specialized machines for the specialized functions within the organization.

The original planning of the machine and the detailed designs should be carefully done to ensure proper function of the machine and also to allow the correct estimates to be made of its cost.

Experience in arc-welded designs may be gained on a gradual and conservative scale in an organization by building shop fixtures and may often lead to marked improvement of the design of the company's major products.

CHAPTER XIV

DIRECT CURRENT AND FLEXIBILITY OF WELDING OPERATIONS

Direct-current welding equipment is a commonly used and well-developed type of welding equipment. Alternating-current welding equipment is also highly developed and in common use in the industry. Much has been said as to their relative merits and usefulness. Each has its particular characteristics and special qualifications so that each has a definite place in the modern applications of welding as a major tool and method of fabrication.

This chapter will be confined for the most part to certain aspects of direct-current welding and some general fields or applications for it together with some of the reasons that usually make some problem best solved by direct-current welding.

As in most problems involving fundamental principles or basic types of equipment, the type of unit developed for welding largely depended upon the first one that was found to be usable in the first operations on which the process or equipment was applied.

In the case of arc welding, the first materials that were used for electrodes were bare wire and, until recent special attachments to alternating-current welding units were developed, the deposition of weld metal from bare-wire metallic electrodes was not practical with anything but a direct-current welding machine. This alone probably had much to do with the fact that direct-current welding preceded the development of the use of alternating current, but other factors also were involved.

Progressive Developments in the Use of Arc Welding.—When a process such as welding first comes into use in industry, there are usually many limiting factors of equipment and knowledge of the fields of application for it.

When arc welding was first taken out of the physics laboratory experimental stage and used in industry, it began as a small-scale repair and maintenance tool. It was direct-current welding equipment, the electrodes were usually metallic pieces of wire

roughly corresponding to the analysis of the material that was being welded, and the whole process was one of experimentation and novelty.

There was a gradual growth in the technical knowledge and mechanics of welding that brought about improvements in both the machines and techniques. Also certain things were found out about the type of wire that served best for making welds.

Among the first uses to which arc welding in this stage of development was put was the emergency repair of broken parts or structures that were brought to blacksmith shops and machine repair shops.

Probably the second step in the development of welding was the fabrication of parts from steel to take the place of broken parts that did not lend themselves to repair by the welding method. By making the whole part by fabricating it from steel, the use of arc-welded design of parts for machines gradually developed.

Another logical and natural growth in the use of welding in such establishments was the building up of surfaces of parts so that they might be used. Gradually it was found that different types of alloy materials could be used for hard surfacing of "heavy-service" parts or worn parts so that they would give a greater life or renew the effectiveness of a worn part. Such a surfacing operation is shown in Fig. 172, where a roller for a track-type tractor is being built up with a hard surfacing deposit.

This type of hard surfacing to increase resistance to wear usually involves either high-carbon steel wire or certain cast alloys or alloy wires (either bare or coated) which, until the present time at least, could not be practically deposited with anything but direct-current welding equipment.

In the natural experimenting that was done in the earlier use of the process, it was discovered that a wide variety of materials aside from steel, such as metallic copper, certain brasses and bronzelike metals, metallic aluminum, and many alloys of steels could be welded with varying degrees of success by using direct-current welding.

It was not a long step in development from the manufacture of parts of machines for repair to the design of machines for complete fabrication by the arc-welded method from the fundamental raw forms of steel or other metals.

Certain improvements in the construction of direct-current machines had been made by the time much of this fundamental design and fabrication of complete machines was undertaken, so that a considerable degree of flexibility and a relatively wide variety of techniques in the use of the machines had been described.

FIG. 172.—Among the earliest uses of arc welding were included repairs of worn parts such as the rebuilding and hard surfacing of this track-type tractor roller, a job done with direct current. (*Courtesy of R. G. LeTourneau, Inc.*)

This basic flexibility is the outstanding characteristic of direct-current welding equipment. It provides the fundamental elasticity brought about by a change in polarity that allows the concentration of the heat of the welding arc to be somewhat regulated and directed either upon the work, known as "straight polarity" (work positive, electrode negative), or upon the electrode, the adjustment known as "reversed polarity" (electrode positive, work negative).

The fact that the first welding machines were direct-current machines had a considerable effect upon another important factor in the development of the arc-welding process, *viz.*, the electrodes.

Development of Arc-welding Electrodes.—The first welding electrodes, as previously stated, were pieces of bare wire that roughly corresponded to the material being welded or that lent themselves to the process at hand.

Early in the experimental uses of welding, it was found that certain types of steel wire produced better welding metal than others and that it was helpful to use certain compounds for drawing compounds in the original drawing of the wire, or else to dip them so that they would have a light washlike or dustlike covering of chemicals on the surface of the wire that tended to stabilize or otherwise beneficially affect the arc during the welding process.

This development was followed by the discovery that heavier coatings consisting of paper, sawdust, or other organic materials and certain minerals, powdered alloys, and salts applied by dipping or extrusion onto the surface of the wire produced superior qualities of welding metal or a wider range of freedom in the use of welding. It was also discovered that greater speed of deposition, greater ductility of weld metal, and in some cases greater tensile strength could be developed in the welding of ordinary structural steel or plates by such a coating and that it was also helpful in the welding of alloys or nonferrous metals.

It was not until the development of such coated electrodes that the use of alternating current for welding became at all practical as a production tool for even the particular fields to which it is especially adapted.

In the development of welding electrodes, it was found that certain electrodes functioned better with direct current when the machine was adjusted to one polarity and that others performed better when the machine was adjusted to the opposite polarity. This offered a still wider range for the application of welding.

Not all electrodes will perform satisfactorily on both adjustments of polarity for direct-current welding machines, but almost all electrodes function reasonably well on at least one polarity adjustment, whereas not all electrodes will operate on alternating-current machines.

Direct-current Welding on Jobs Using a Wide Variety of Materials.—Because of its wide adaptability, the use of direct-current welding is especially suited to certain types of organizations or departments within large organizations whose work includes a large variety of materials and jobs.

An organization that operates on a job-shop basis or much as the earliest users of welding, the automotive repair shops, garages, small job shops, and repair and maintenance shops, which have a large variety of sizes, shapes, forms, and thicknesses of ferrous materials to be repaired, or which have jobs involving different types of specially alloyed ferrous materials or nonferrous materials, find direct-current equipment applicable to their problems.

Such organizations may be the repair-job shops that do regular repair work on the general run of household appliances and farm machinery, automobile fender and body repair work, or any ordinary industrial repair work that comes to them. These naturally include ferrous and nonferrous jobs.

Other organizations that have wide varieties of materials may include industrial welding job shops, which because of special alloy fabrication or nonferrous work find use for the adaptability of direct-current welding in the normal run of their variety of jobs.

Within large manufacturing organizations, the repair and maintenance departments frequently have many of the same problems that the garage or automotive repair organization would have and, therefore, use direct-current welding.

Departments in large manufacturing organizations that make jigs, dies, tools, and fixtures also find a variety of welding problems which at times practically require the widest variety of adaptability that can be furnished by any welding equipment.

In the blanking die shown in the foreground in Fig. 173, a direct-current welding machine was used to apply the tool-steel weld deposit that forms the cutting edges of the die (the narrow light-colored margin shown on the top inner surfaces of the die-cutting edge).

These general applications and this general description of the type of organization that finds most advantageous use of the direct-current welding equipment represent only a general coverage of the problem. Naturally, there are many other users of direct-current welding, since any welding job can be done

with a greater or less degree of practicality with direct-current welding equipment.

The discussion so far has included only organizations whose use of direct-current welding is predicated on the variety of their problems. There are many which use this type of equipment because of the volume of specific types of welding which, up to the present time at least, have been more satisfactorily accomplished by the use of direct-current equipment than any other available. Some examples of such jobs will be described in the next paragraphs.

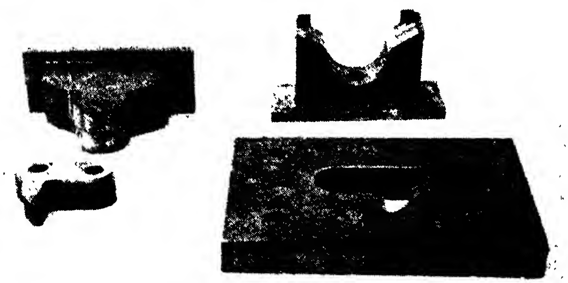


FIG. 173.—Jig and fixture or tool- and diemaking departments have a wide variety of problems, one of which is illustrated by the hard surfacing of the cutting edges of the blanking die in the foreground, a job normally done with direct-current welding equipment. (*Courtesy of R. G. LeTourneau, Inc.*)

Some Special Welding Production Jobs Using Direct Current. Based on past experience and contemporary practice that grows out of the available facilities (especially the available welding electrodes), there are certain welding problems that, at present at least, are largely direct-current welding applications.

Welding of metallic copper to the extent to which it is done at present appears most successfully accomplished with direct-current equipment.

The welding of brass and the weldable bronzes such as Everdure, Herculoy, and Olympic bronze, for example, using the carbon arc or the metallic arc, also are usually direct-current welding applications.

In ferrous-metal welding using the ordinary weldable steels, light-gauge sections that include tubing, sheets, structural shapes, plates, or strips have at least until recently been most successfully

welded with direct current because of the wide flexibility of the direct-current equipment and electrodes.

Applications such as the light-gauge blower shown in Fig. 174 are good examples of welds where direct-current welding equipment seems best to serve the purpose.

The recent development of a high-frequency current superimposed over the regular low-frequency welding current of

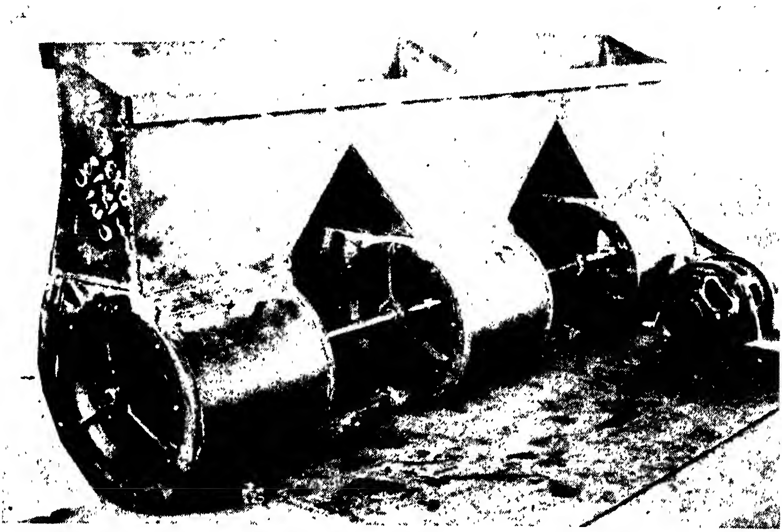


FIG. 174.—Until recently at least, direct-current arc-welding units alone were satisfactory for fabricating light-gauge material into equipment such as this large light-gauge steel blower. (*Courtesy of R. G. LeTourneau, Inc.*)

alternating-current units suggests that there may be some use for alternating current in such fields in the future.

The welding of light-gauge ferrous material using the carbon arc with or without filler wire is another direct-current application that produces an economic margin over some other methods of welding available to fabricators.

The uses of light-gauge low-carbon steel, especially where lap joints may be made or formed joints used which may be melted down without the use of filler wire by the heat of the carbon arc, often represent good applications of direct-current welding.

Most stainless-steel fabrication and other high-alloy steel welding applications have, until the present at least, been considered to be direct-current welding jobs. This also applies

to many of the special welded structures used in the chemical industries today or for other structures that are clad with high-alloy or nonferrous liners which are weldable, and yet for which there have not been satisfactory electrodes, procedures, or equipment developed with alternating current up to the present time.

FIG. 175.—The mass-production hard surfacing of these cutter blades for earth-moving equipment is accomplished with direct-current welding. (*Courtesy of R. G. LeTourneau, Inc.*)

At present, most high-carbon welding electrode deposits have been considered more satisfactorily accomplished by direct current than by other means, since the high-carbon electrodes mostly fall in the same category as the high-alloy tool-steel weld deposits or other highly specialized and highly alloyed materials.

Some surfacing operations are done in sufficient quantity to justify a mass-production handling, as is exemplified by Fig. 175, which shows cutter blades for earth-moving equipment that are hard-surfaced by the use of alloy electrodes and direct-current machines. Although it is possible to deposit such materials by using alternating current, it is not so satisfactory or so efficient as with direct-current welding equipment.

Wherever carbon-arc cutting is used as a regularly employed cutting tool, such as the cutting up of thin-gauge structures for scrap, or the cutting of risers from alloy-steel castings where the ordinary heat of the flame-cutting equipment will not satisfactorily burn the risers off, direct-current welding equipment provides the best source of power for such carbon-arc cutting.

Field Fabrication and Erection of Welded Structures.—A large and important phase of the welding industry that uses direct-current welding equipment extensively is that of fabrication of welded structures in the field or the erection of prefabricated substructures into completed units.

This widespread and common usage of direct-current equipment for field erection is probably based upon at least two important reasons.

First, the available source of power for welding in many of the out-of-the-way places where construction of new projects is undertaken is frequently not suited to the use of alternating-current welding equipment.

It is not unusual to find that there is no electrical power available and that the welding current must be generated by gasoline or Diesel power and converted into usable electric power for welding. By far the greatest number of units for the generation of this power and the conversion of it into a satisfactory source for arc welding are direct-current motor generators.

The erection of the prefabricated steel building shown in Fig. 176 was best suited to the use of direct current as a welding source (1) because of its being made from thin-gauge material that was welded into substructures prior to being assembled by the erection crew in the field as shown in the picture and (2) because of the available power.

The type of operation shown in Fig. 177, where a large drainage pipe is being laid, is another example where portable welding equipment that manufactures its own power on the job was almost a necessity. For this reason, it was a direct-current application. This is true of almost all pipe-line welding construction and other such applications of welding in the field.

A second reason for widespread use of direct current for field-erection welding is probably the fact that welding electrodes that gave the weld metal deposits having the acceptable physical characteristics were first developed for direct-current welding

units. Owing to a wide acceptance and a well-demonstrated reliability of these electrodes in performance when used on important construction or erection jobs in the field under somewhat less favorable conditions than would normally be found in factory or shop conditions, there has probably been a trade preference for the direct-current welding and welding electrodes for such jobs, since they almost always involve some degree of public liability or code control.

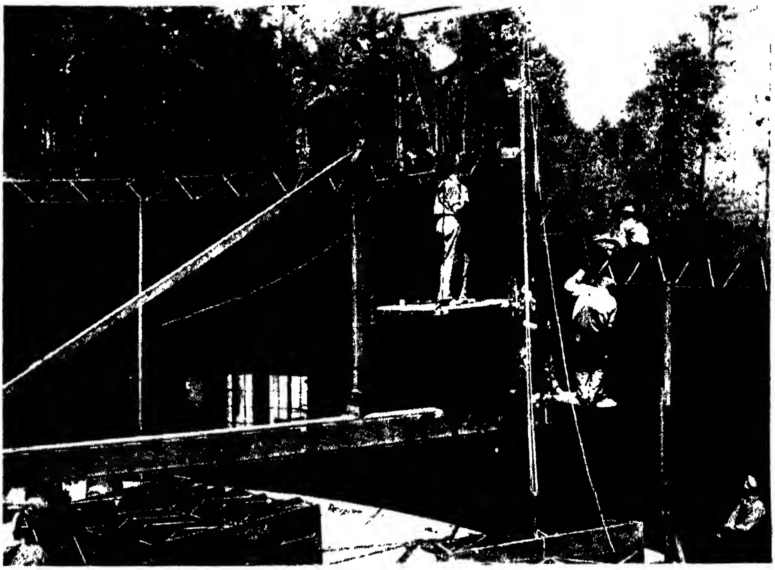


FIG. 176.—Erection of welded structures in the field is most commonly done with direct-current welding equipment since suitable power for arc-welding transformers is not always available. Direct current on this light-gauge structural application served the purpose well. (*Courtesy of R. G. LeTourneau, Inc.*)

Field Maintenance Service for Weldable Products.—Still another field of operation that has become increasingly important in the past few years is the maintenance and repair service for weldable products, either made originally by welding or fabricated from weldable steels, that require repair after service in the field, where it is more practical to do the welding on the job than it is to take the unit to some repair shop.

Here again, direct-current welding equipment has preferentially established itself because the portability of such units makes it convenient for service trucks to be taken to repair jobs in the field.

FIG. 177.—Portable direct-current welding units have contributed greatly to the welding of drain pipes such as this one or other pipe lines and similar construction work far from normal sources of power. (*Courtesy of R. G. LeTourneau, Inc.*)

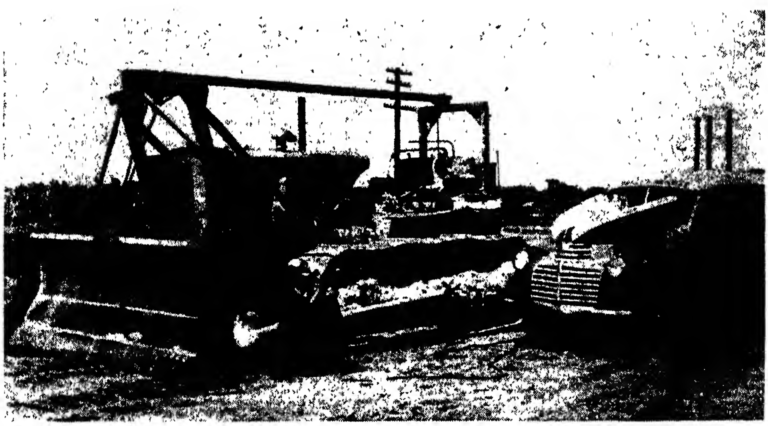


FIG. 178.—For repair by welding in the field, the portability and flexibility of direct current accommodates the wide variety of field repair from thin fender material to heavy constructional material such as this tractor and earth-moving unit, and also nonferrous and alloy materials. (*Courtesy of R. G. LeTourneau, Inc.*)

There they generate their own direct-current welding power and make possible the performance of such repairs as are shown in Fig. 178. This is a typical field repair using a portable arc-welding service truck equipped with a direct-current motor-generator unit that is driven from the transmission of the truck and produces satisfactory welding power for such repairs as are necessary on units such as the tractor and earth-moving unit shown being welded.

The adaptability and flexibility of the direct-current welding equipment and electrodes make it possible for a tremendous variety of welding work to be done with such portable field-maintenance repair units.

In the normal use of such a service unit, a wide variety of jobs may be encountered, ranging all the way from light-gauge steel such as automobile fender or body materials to large heavy sections of steel. A wide range of alloys of steel may present themselves in the repair of a variety of construction or other field operating equipment, and such specialized operations as the welding of hard surfacing material or high-carbon deposits may be a part of the regular work for such service trucks.

The problems of the removal of dirt, of welding in all positions, and of cleaning paint, oil, rust, etc., from units being repaired make the field welding applications difficult and place a premium on the flexibility that is characteristic of direct-current equipment.

In the same way that the welding truck shown in Fig. 178 lends itself to field-maintenance welding, so also there are portable welding units for railroad track and equipment repairing, open-pit or underground mining equipment repairing, and many other applications requiring the use of portable repairing or construction units.

CHAPTER XV

MASS PRODUCTION WITH ALTERNATING-CURRENT WELDING

During the period of change that has been brought about by the general acceptance of arc welding as a method of producing much modern machinery and equipment—especially heavy machinery—some factors in the operation of welding equipment, which on the relatively small-scale operation of several years ago were of minor importance, constitute differences of major economic importance in today's operations.

In marked contrast to operation some years ago, the operations of arc-welding establishments on a mass-production basis are characterized by the following features:

1. The use of a large number of arc-welding machines.
2. The use of hundreds or thousands of tons of structural steel as rolled at the mill.
3. Large quantities of arc-welding electrodes. (From a few thousand to several million pounds a year.)
4. The use of large amounts of electrical power.
5. Often several hundred welding operators, frequently including the training of large numbers of operators.
6. The use of jigs and positioning fixtures to permit the use of greater amperages and larger electrodes for regular production work.
7. The manufacture of a large variety of shapes, sizes, and quantities of parts and structures in the same plant.
8. Controlled procedures, often based on time studies and operating to close time schedules.
9. The use of coated electrodes instead of bare electrodes.

As pointed out in the previous chapter, there is a definite place in the welding industry of today for both direct- and alternating-current welding equipment. Direct-current welding is characterized by a certain advantageous flexibility and adaptability; yet for some large and important fields of welding application, alternating-current welding has significant advantages, especially

in the large-scale mass production of welded goods from ordinary structural steels, both carbon and low-alloy high-tensile steels. New developments in superimposing high-frequency current over the ordinary low-frequency alternating current seem to indicate that alternating-current welding will be applied to a wider variety of welding problems in the future than in the past.

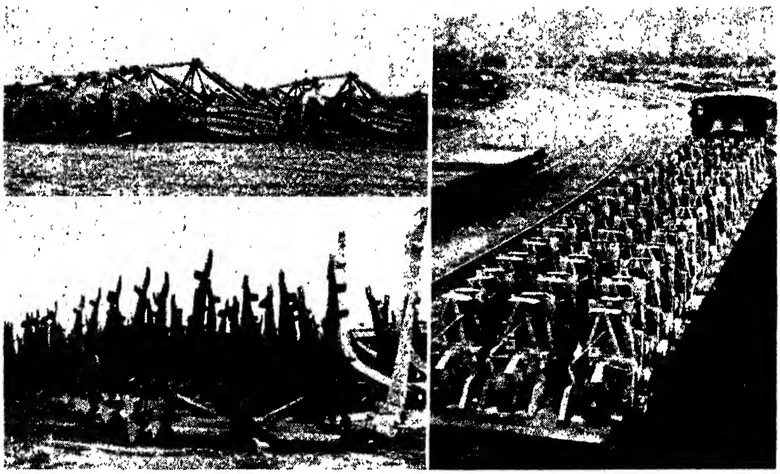


FIG. 179.—The all-welded, high-speed power control units (right) and scrapers (upper) and angledozers shown here are only a fraction of a week's mass-production output of one plant. Of 300 welding machines in this plant, 290 are alternating-current machines. These 290 machines deposit about 45,000 lb. of electrodes per week. (*Courtesy of R. G. LeTourneau, Inc.*)

There are several reasons for the large preponderance of alternating-current machines (see Fig. 179) being used by some leading welding organizations who operate on a mass-production basis. Most of these reasons are comparatively minor when viewed in a comparison of one machine with another, and most of them deal with the quality or speed of operation rather than with the inherent measurable differences between the machines.

There has been much careful study and research completed on the differences between alternating-current welding machines and direct-current welding equipment, and a close and unbiased evaluation of the data seems to lead to the conclusion that there are few differences of significance between them as a means of making good welds on an economically practical basis when both are being used on materials that both will weld satisfactorily.

Both have been tried and tested on a large enough scale and wide enough variety of work (see Fig. 180) to prove that either is practical for modern arc-welding practice from the "quality-of-welding" standpoint.

However, considering the mass production of the machinery and the equipment aspects of arc welding, there seem to emerge three advantages in favor of alternating-current welding equipment: two are measurable and easily defined, *i.e.*, (1) cost of maintenances and (2) power consumption; and one is variable and well recognized but not fully discussed in terms of its effect on mass production, *viz.*, (3) the practical elimination of arc blow.

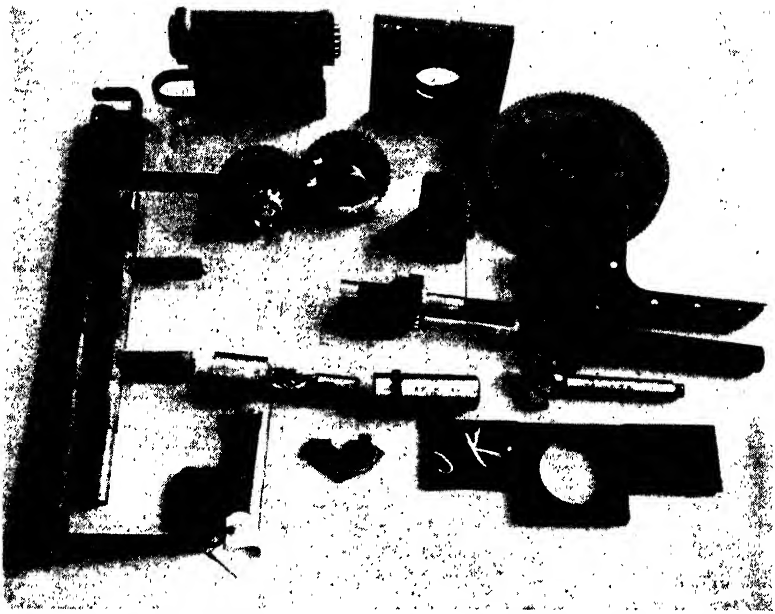


FIG. 180.—Here are a few examples of the great variety of parts that can be produced economically with alternating-current welding equipment. Note that there are relatively thin sections and thick sections, fast-moving parts either heat-treated or as deposited, large parts and small. (*Courtesy of R. G. LeTourneau, Inc.*)

The differences in maintenance cost on 100 alternating-current machines of the transformer type, compared with either direct- or alternating-current motor-generator type machines that have a comparable capacity, over a period of 10 years amount to a sizable difference in costs chargeable to overhead expense. The

first cost of either type of machine in large heavy-duty machines is about the same and can be written off as a depreciation in about the same length of time. (There seems to be an advantage in first cost of small machines in favor of alternating-current units.) But the additional cost of maintenance of the motor-generator type of machine, together with the time lost from productive operation while servicing is being done and repairs are being made, leaves a valuable margin in favor of the transformer machines when 50 or 100 are involved.

The comparison of a motor-generator alternating-current machine with a direct-current motor-generator machine of similar capacity shows no significant margin in initial cost or in maintenance, yet in some cases the purchase of a motor-generator type alternating-current machine may be justifiable for other reasons.

A motor-generator type alternating-current machine has the operating advantage of an alternating-current machine by practically eliminating arc blow; it also has the advantage of making better welding conditions with a variable current supply having short variations in it which the momentum of the motor and rotor of the machine tend to level out better than does a transformer type machine.

Power Consumption.—A difference in power consumption between direct-current motor-generator welding machines and alternating-current transformer units of the same capacity, on mass production, seems to be discernible in favor of the alternating-current transformer.

Although the difference is not great, even a small percentage in favor of the transformer machine on several million kilowatts of power per year amounts to a noticeable economic factor. There apparently is no significant difference between alternating- and direct-current motor-generator welding equipment so far as power consumption is concerned.

Elimination of Arc Blow and Mass Production.—Arc blow in itself does not seem at first to be an important factor, and yet in the mass production of commonly weldable carbon-steel structures, especially where large plates and modern, curved, functional designs are used, or where combination setup and positioning fixtures are used, it has its definite effect upon either the quality of welds deposited or the time it takes to make the welds.

The effects of arc blow enter into almost every major phase of mass production by arc welding, and the practical elimination of it by the use of alternating-current machines makes welding on large operations enough simpler to be a factor of considerable importance. In the following paragraphs these major phases will be discussed separately, as affected by the arc blow.

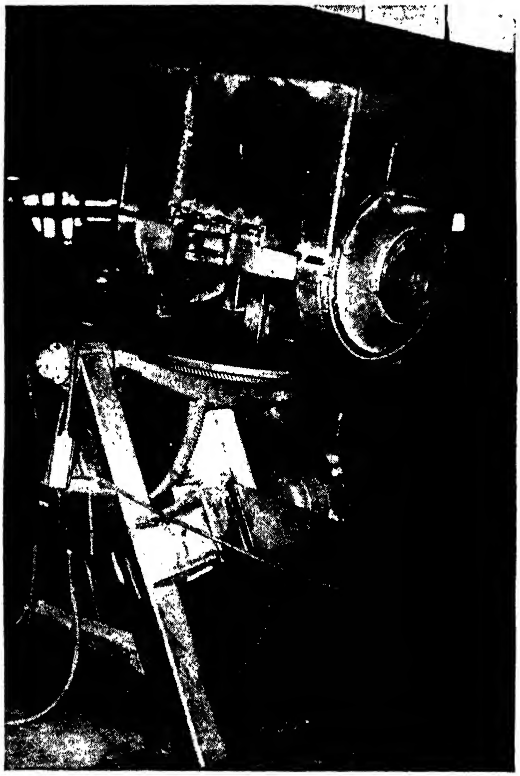


FIG. 181.—This all-welded low-alloy high-tensile steel transmission case must withstand the most punishing stresses and service without weld failures. Depositing welds 2½ ft. down into the bottom of the inside of the case must be free from arc-blow interference to assure the best welds and tie-ins possible. (*Courtesy of R. G. LeTourneau, Inc.*)

Arc Blow and Freedom of Welded Design.—The use of arc welding in the manufacture of complex pieces of machinery requires all the freedom of operation in the actual welding process that can be practically obtained.

The fact that arc blow is more often experienced in depositing welds in small recesses or in deep corners, or in structures where

units of curved design help to form magnetic fields, makes it desirable that it be eliminated as far as possible in the selection of the manufacturing equipment. Modern design of complicated machinery, involving curved plates and members and often deep and complex recesses and a variety of sizes and thicknesses of plates, offers a difficult enough welding job under the best of conditions, without including variable factors that can be effectively eliminated.

The large tractor transmission gear case shown in Fig. 181, fabricated entirely by arc welding, involves the deposition of welds on the inside of the case on curved members at a depth of more than 2½ ft. from the nearest opening to the outside. In order to achieve the greatest economies of material and maintain the smallest clearances and yet the most effective design possible, this case must be welded with the highest practical degree of perfection.

The fact that it is made of low-alloy high-tensile steel further requires that the welded joints be as near 100 per cent efficient as possible, especially in the corners and at the points where welds tie in with one another, where stresses may be concentrated.

The fact that arc blow usually gives less difficulty in relatively open welds along straight lines, and more difficulty in the corners where welds are started or finished and where they must tie into other welds, presents a definite problem to the designer. The place where the weld must be most reliable is where stresses are most likely to be concentrated. Often the end of a weld that finishes in a deep corner, or that ends in a square inset corner where structural shapes are being used such as shown in Fig. 182, is the place where arc blow is likely to give difficulty.

In the hands of a skilled operator, the deposition of a good sound weld in a deep corner, such as shown in Fig. 182, may be done with a direct-current machine if he encounters arc-blow trouble as he approaches the corner; but it will require judgment on his part to know how to manipulate his arc and his electrode, or how to change the location of his ground in order to break up the magnetic field that is causing the interference with his control of the arc.

By the use of alternating current with its practical elimination of arc-blow difficulties, the probability of poor tie-ins, such as shown in Fig. 182, is greatly reduced. Such defective welds may

or may not be as apparent as the one shown in Fig. 182 and, therefore, at times may pass inspection and yet have an inherent weakness because of poor penetration into the bottom of the corner where stresses actually will be concentrated most severely. The reduction of the probability of such defects provides a degree of freedom in design and the possibility of a reduced factor of

FIG. 182.—This weld was defective when the first pass was tied into the adjacent welded joints. Arc blow may have caused the lack of control of the arc that resulted in this defect. Subsequent passes did not improve this weld—one where stresses are concentrated and tie-ins must be good. (*Courtesy of R. G. LeTourneau, Inc.*)

safety in the deposit of weld metal on such joints that constitutes a distinct advantage in favor of the alternating-current welding equipment.

The time required to redeposit the weld in Fig. 182 and to cut it out is lost time under any circumstances. It will take longer than the original weld should because of the fact that additional heat has been concentrated in that area, and it may result in an imperfect weld in the end owing to damage of the metal in the vicinity of the weld.

Arc Blow and Freedom of Design of Fixtures.—The modern practice of building welded units in many simple substructures that may be tacked together in setup jigs, positioned for most

favorable welding as substructures, and then combined into finished machines in large setup and positioning fixtures, such as shown in Fig. 183, requires an additional measure of freedom from arc blow and its interference with depositing good sound welds.

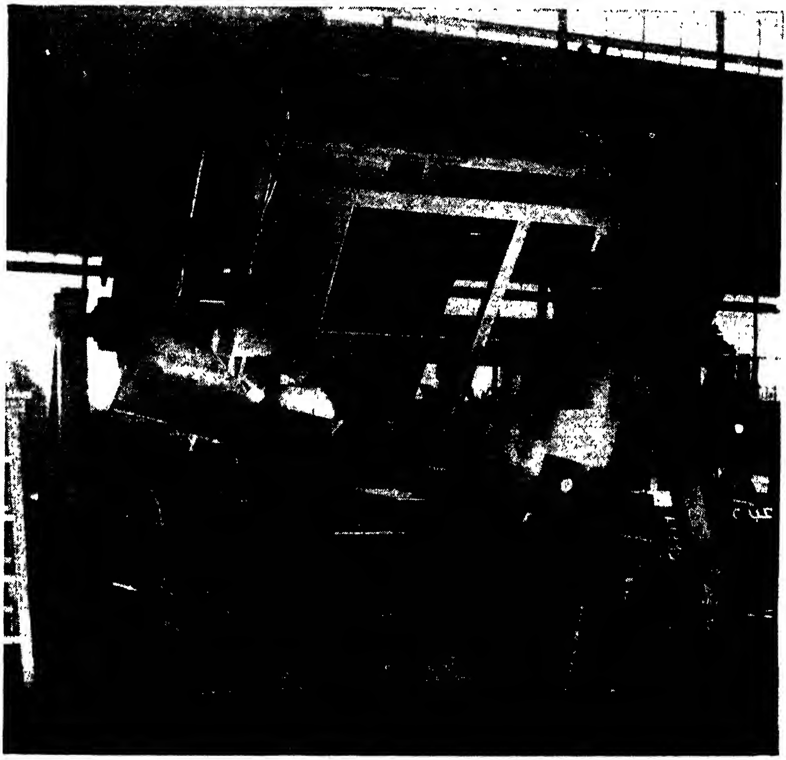


FIG. 183.—The substructures that make up the final body of a large earth-moving machine are shown in this "body setup and welding jig." The form of the substructures and the many contacts of the jig plus the framework of the jig offer possible sources of magnetic fields during welding. Alternating-current welding equipment gives almost arc-blow-free welding even with large electrodes and high amperage. (*Courtesy of R. G. LeTourneau, Inc.*)

The parts for a structure may be set up in a simple part-positioning fixture that has several stops against which the individual parts may be placed quickly and positively without measurement or without a special positioning study on the part of the operator. Often such a fixture may be made in such a way as to allow the complete welding of the structure while it is

still in the setup jig by having the setup jig on trunnions or hinges that allow the complete positioning of each weld for down-hand welding.

The result of the use of such fixtures is commonly known to greatly increase production efficiency by reducing both setup and welding time. Large, fast-burning welding electrodes may be used for the deposition of such welds. Each of the stops on the setup and welding fixture forms contact with the plates being welded, and the framework usually borders the part being welded. These contact and framework parts, together with the structure itself (see Fig. 183), often cause the formation of troublesome magnetic fields when using direct-current welding equipment which are almost eliminated by the use of alternating current.

Whenever an operator finds it necessary to break his arc and stop welding or to study the manipulation of his arc in order to deposit a weld because arc blow interferes, or whenever he finds it necessary to readjust the location of his ground to break up the magnetic field, he is losing time which is expensive. The use of alternating current gives greater freedom in the design of fixtures for setting up and positioning for welding of parts than does the use of direct-current welding equipment.

Arc Blow, Size of Electrode, and Speed of Welding.—A very definite relationship between the increase in size of electrode and increase in speed of deposition of weld metal is commonly recognized in arc-welding practice. It is also commonly known that if a structure may be welded with the majority of its welds in the down-hand position, larger electrodes may be used with assurance of good welding; that it is easier for the operator to deposit welds in the down-hand position; and also that the appearance of such welds is ordinarily considered to be better than if they are deposited in the horizontal-fillet, horizontal, vertical, or overhead position. With each increase in the size of the electrode and the attendant increase in the amperage used for its deposition, there is also a definite increase in the probability of an arc-blow interference in the deposition of a weld.

With the common use of large electrodes, the increase in the arc-blow problem is considerable and on a mass-production scale becomes a problem of real economic importance.

The welding shown in Fig. 184 is being done in a deep recess on plates ¾ to 1 in. in thickness and in a part of the unit where there

is known to be the greatest concentration of stresses in the entire unit. The welding is done with 450 to 500 amp. and $\frac{5}{16}$ by 18 in. electrodes and is done inside a positioning fixture without any worry on the part of the operator, the inspectors, or the designers as to poor penetration caused by possible arc-blow interference. This is a splendid alternating-current application,

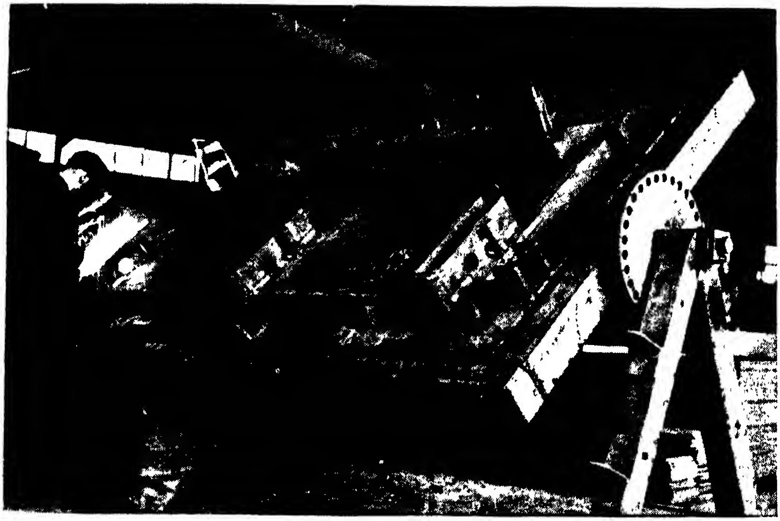


FIG. 184.—Down-hand type electrodes, $\frac{5}{16}$ by 18 in. long, and 450 to 500 amp. of power, positioning fixture, and alternating-current welding equipment develop real speed and welding economy on this job. The "inside" welds shown being made on the 1-in. plates are among the most heavily stressed in the unit. In this place, arc-blow elimination is doubly important: (1) for quality of welds, (2) for speed. (*Courtesy of R. G. LeTourneau, Inc.*)

because it would almost certainly involve considerable arc-blow interference with direct-current welding equipment.

Arc Blow and the Training of Welding Operators.—One of the largest problems that has faced the welding industry in the past several years has been that of training a sufficiently large number of operators to do the welding that has been brought about by the great expansion of the industry.

This training process is one that, under any circumstances, represents a considerable investment in time and effort. Anything that can be done in the organization of such a training program or in the purchase of the equipment that shall be used by these men on the production line to simplify such training is a

good investment. It will reduce the length of time required for the student welder to become sufficiently proficient to do simple welding, and from then on he can learn on the job.

The problem of arc blow can be practically eliminated by the use of alternating-current welding machines, and in the training of new welding operators the removal of the confusing problem of arc blow represents a considerable element of economy.

The unpredictable (at least to the untrained operator) nature of arc blow adds a mysterious force that seems to make the process of depositing metal and controlling the arc a curiously fluctuating process. At a time when the student operator is

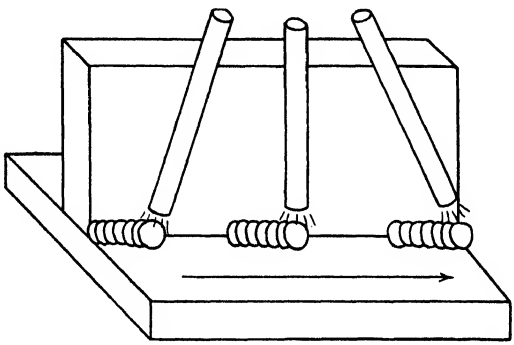


FIG. 185.—By holding the electrode in the three successive relative positions to the joint as shown left to right, arc blow is minimized when it is encountered. Alternating-current equipment practically eliminates this extra series of motions by reducing arc blow to a minimum. Note that the first (left) and third (right) positions are both contrary to the common position in which the electrode is held where arc blow is not encountered.

giving his every attention and effort to learning the complex problem of arc length, speed of arc travel, angle of electrode to the work, manipulation of the electrode, watching the crater and the slag form, and all the other things that of necessity must be learned, to confuse the picture with the unpredictable and variable problem of arc blow is to lengthen the training program unnecessarily.

An examination of the several textbooks commonly used for operator schooling indicates, by the space and illustrations devoted to it, that arc blow is a factor to be dealt with in detail and with care.

One of the suggested methods of manipulation to avoid the difficulty of arc blow is illustrated in Fig. 185 where, in the first

end of the weld, the electrode should point toward the end of the joint and be carried at an angle that directs the welding metal toward the place where the joint is begun. As the weld progresses, the electrode is swung into normal depositing position which is a less acute angle, so that the electrode points more nearly down on the joint, and then as the end of the weld is approached, the electrode is to be swung so that it points forward to the end of the joint. This method is spoken of as being quite effective by many experienced operators, and yet it involves, for the new welding operator, a variable procedure that interferes with the habits he must form in the deposition of metal in the average joint if he is not having to combat arc blow. The position of the electrode at the end of the weld is contrary to the normal position where no arc blow is encountered. By the use of alternating-current welding equipment, this variable is practically removed and, therefore, does not present an additional, confusing problem to the student welding operator.

Polarity of Electrodes and Machines, and Training of Arc-Welding Operators.—Additional subjects that require a certain amount of time and attention on the part of a student welding operator are polarity of electrodes and the setting of the polarity of a machine wherever direct-current welding machines are used.

Until recently, the justification for the use of direct-current welding machines because of the lack of satisfactory alternating-current arc-welding electrodes for the majority of mass production of ordinary steel products by welding was valid. This has been practically eliminated in the past few years, since there are now available electrodes that can be used with alternating current to do a sufficiently wide variety of welding operations to include almost every mass-production welding problem involving ordinary carbon or structural steels.

In training operators for specific mass-production welding jobs, there is little object in spending time or confusing the operator with the subject of polarity and the ramifications of straight and reverse polarity electrodes and their various characteristics. For practical purposes, for mass production of machines and other welded structures from the ordinary structural steels of today, alternating current effectively sidesteps the old problem of straight- or reverse-polarity electrodes and allows the student

welding operator to learn the thus simplified fundamentals of welding metal deposition more quickly.

Arc-welding and Mass-production Schedules.—With the development of mass production of welded structures, including the formation of line assemblies in the welding process, where substructures are set up and welded and then placed in larger assemblies and welded into the final, completed unit, the necessity

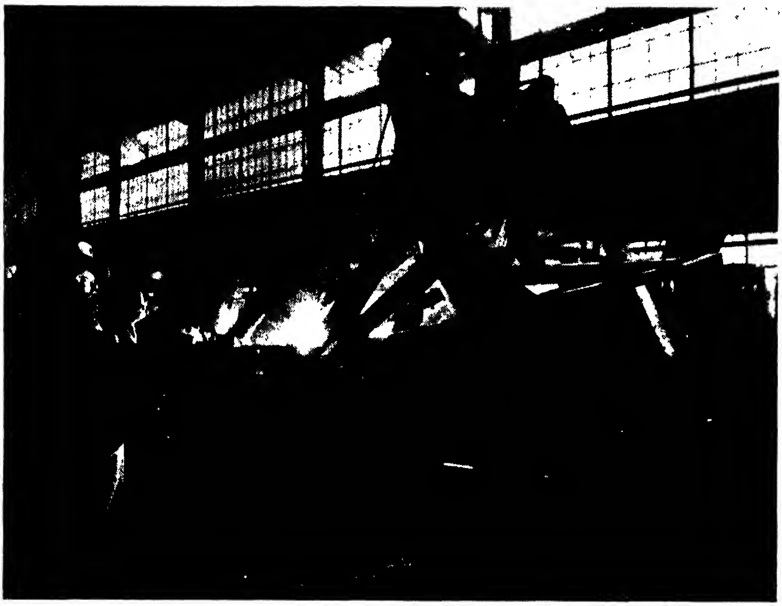


Fig. 186.—By control of procedures and removal of all unnecessary variables, followed by careful time studies on structures such as this part of an earth-moving unit, reliable and well-balanced production schedules can be set up for their manufacture. (*Courtesy of R. G. LeTourneau, Inc.*)

of standardized procedures and the need for reliable time schedules has become an item of major importance.

By eliminating from the welding process on all substructures and structures all of the unpredictable variations that can be practically eliminated, much more scientifically sound and reliable schedules of production may be established. The elimination of the unpredictable and variable phenomenon or arc blow from the welding process by the use of alternating-current welding equipment is a step toward standardizing schedules of production.

Figure 186 shows one of many structures that are being produced on a basis of schedules built from time studies. It is one which is produced on a schedule that has been determined by first establishing a definite control on all the variables that can practically be controlled, including weld size, fit-ups, type of electrodes, size of the electrode, machine setting, and position in which the weld will be deposited, and then determining by time studies how long it takes to make each unit. By removing from it the variable of arc blow, with its attendant lost motion of readjusting ground or of special manipulation to take care of certain conditions that arise in the production of these parts, time has been saved and a greater degree of reliability of production schedules is experienced in the manufacture of these structures.

It is also possible to build up synthetic time values for mass production that may be applied to machines that are being designed and are not yet built, where the arc blow loss of time using direct-current welding might be difficult to predict because of the specific nature of the design before the unit has actually been put into production. The use of alternating-current welding thus allows a reliable prediction of the time and facilities required for its mass production, as well as of the cost.

CHAPTER XVI

CAREFULLY CONTROLLED ELECTRODE COMPARISON TESTS ARE PROFITABLE

No item is of more fundamental importance in the arc-welding process than the electrode itself. No item is more deserving of an objective and thorough test before being adopted for any specific welding application, yet many thousands of dollars of potential savings and profits are lost each year for want of the few simple observations required to make a practical test on the electrodes used on most ordinary arc-welding applications.

There are many broad, general principles of arc welding such as the materials used, the machines used, the design of the particular application, the factors of safety involved in the design, and the procedure of application of weld metal that allow any one of a large variety of electrodes to serve passably on a given application; but of that large variety there are one or two that will serve most economically for one or more reasons. The difference in actual cost of the finished job, using the most economical electrode instead of some of the others less adaptable to that job, is almost always large enough to be significant, even if the job involves only a small amount of electrodes.

These differences in cost do not arise primarily from the original cost per pound of the electrode, except perhaps in cases of alloy welding or hard surfacing, but rather from the manner in which its characteristics fit the special requirements of the application. Each welding shop or factory and each job in such a shop is unique in some respects. Elements of design, materials, fixtures, and position of joint when welded vary on all but the simplest jobs. Elements such as the type of welding machine, skill of operators, source of power, and general procedure vary widely from one establishment to another. The result of all these variations is that the electrode that is best for one shop may not be best for another, and that the electrode that is best for some types of weld in a given shop may be much more expensive than another for certain other applications in the same shop.

The importance of an intelligent choice of electrodes for a given job can hardly be overemphasized. In the first place, an electrode is essential raw material which, when deposited in the finished product, actually predetermines the strength of the unit, since it is the material that joins the rest of parts of the unit.

This raw material usually costs less than 16 cents per pound as purchased, but when it is actually in the deposited condition on a finished piece of equipment it costs 75 cents to $2.50 a pound, depending upon the type of job in which it is used, and—of great importance—how it lends itself to the application in which it is used. A small difference in speed and efficiency of deposition alone may make as much as 15 or 20 per cent difference in the "as-deposited" cost per pound of weld metal. The inherent difference is often found to be a characteristic of the electrode as it applies to a given job.

The first consideration, given the equipment and personnel of the shop, naturally has to be an electrode that will produce joints having physical properties the same as (or better than) those of the materials being joined together.

Other considerations, such as appearance of the welds made by average operators in the shop, cost of deposition, cost of cleaning, and cost of finishing enter into the analysis.

Equipment and Personnel for Simple Shop Test.—In such an analysis of electrodes, a few simple tests, if they are made accurately, are much better than none. By the use of simple tools for measuring and timing such as are shown in Fig. 187, tools that can be found in even the smallest welding establishment, enough comparative information can be gathered on a set of electrode samples in a short time to eliminate completely some electrodes for a given application and to permit an intelligent choice among the others. The testing equipment that should be used for a complete and practical testing for larger users of electrodes will be discussed later.

The testing and comparing of electrodes should be done by a man who knows the details of the welding problems and related processing in the shop. He does not necessarily have to know how to weld, but he does have to know how to interpret the things that can be observed about a welded joint in its various stages of completion. He should observe someone else use the electrodes under consideration if possible, since it is difficult for a man to

check burn-off rates accurately when he is actually burning the electrode himself. If he can weld and is doing welding regularly at the time, he should weld with the same electrodes to check for himself the handling characteristics of each.

Electrode tests should be comparisons. Usually the shop is using some electrode for a certain application. A possible substitute electrode for that application should always be compared with the one in use. If the man who checks the electrodes is sure he can make the tests exactly the same every time and will keep exact records of each electrode tested, he can set up a

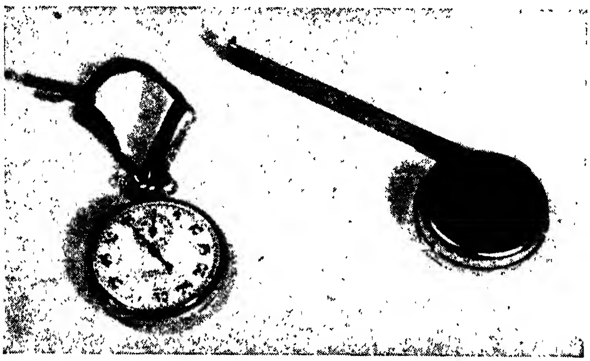


FIG. 187.—These simple measuring devices are all that are required to make comparative measurements on electrodes by which the user of only a few hundred pounds a year may realize important savings. (An ordinary pocket watch serves well if no stop watch is available.)

procedure and run each new electrode singly, without testing the one in regular use every time, and thereby cut down on the time required for such tests; but he should have the results of several tests on his standard electrode that agree closely before he feels sure that he can compare all new ones with it without checking them side by side.

The one who conducts the tests on electrodes should have in mind clearly what that electrode is represented to be, and what the proper operating conditions for it should be. He should also have a clearly defined plan of testing, which should not be subject to alteration from test to test.

The ideal plan of approach to these tests is to have the electrodes that are to be tested, with complete general information as to type, etc., presented to the purchasing department which, in turn, passes the samples and information on to the man who is to

make the tests. In order to make the tests truly objective, the name of the electrodes should be omitted from the information given the man in the shop. He then should make the comparative tests and bring back an objective, factual report and recommendation to the purchasing department, explaining exactly how the sample electrode compares with those used in the shop as standard. The purchasing department can then

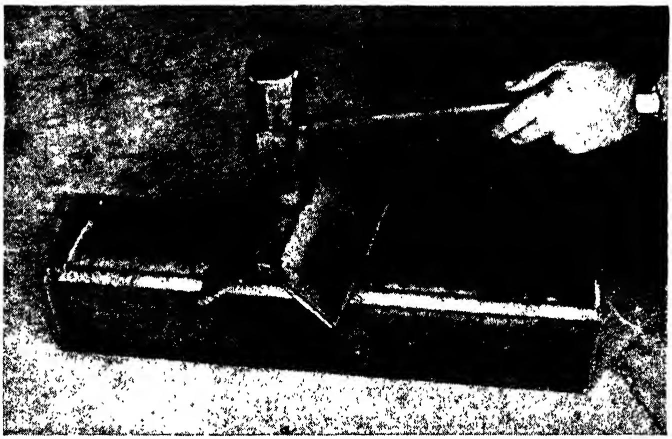


FIG. 188.—A heavy press or an expensive testing machine is not needed to see the inside of test welds. A test piece can be broken with a hammer to reveal many important details about the weld. (*Courtesy of R. G. LeTourneau, Inc.*)

proceed to consider them in the light of how they serve the exact needs of the shop.

Any job involving even as small a quantity as 100 lb. of electrodes deserves to have special consideration, since that amount, when actually deposited as weld metal, will represent an investment of $40 to $150 in labor, power, electrodes, and overhead. Whether the cost is $40 or $150 depends to a certain degree on the characteristics of the electrode. A little study can often make a big difference as to just where between $40 and $150 the actual cost will be.

The actual testing procedure depends on the equipment available for making such tests and on the amount of electrodes involved. Even the smallest welding electrode consumer has a watch, a measuring rule of some sort, and equipment for breaking or cutting through welds, even if the latter is only a jack or heavy hammer with which welded joints can be broken for examination.

Figure 188 shows how test welds can be broken open with a hammer.

Measurable Elements of Cost Checked in Simple Test.—The following elements of cost can be checked by these three simple tools:

1. *The rate of burn-off* of the electrode can be timed with a watch (a stop watch is better). The actual number of seconds

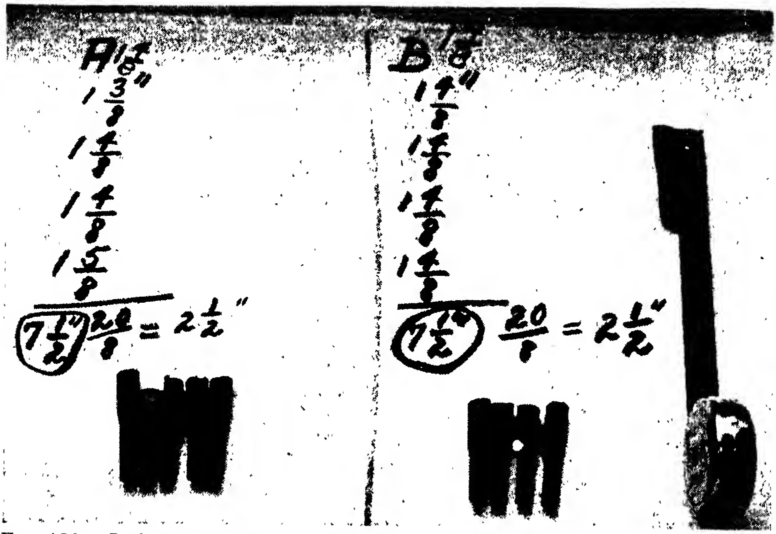


FIG. 189.—In burn-off tests, each electrode butt should be saved and measured carefully so that the total inches of electrode actually burned can be calculated.

required to burn each of at least three electrodes of each kind being tested should be observed and recorded. The electrodes should all be burned down to about the same length of butt, an average of 1¼ in. for example, in order to make the burn-off time truly comparative. The burn-off rate per pound can then be determined by finding the number of electrodes in a pound. Each kind of electrode should be burned off at the machine setting at which it operates best on the particular weld being made for the test.

All electrodes tested should be deposited on the same kind of weld, and the weld should be typical of the welds made in the shop. This gives them all the same conditions and allows their individual differences to be measured. Careful timing and

recording and careful measurement of electrodes and butt lengths as shown in Fig. 189 must be made because the most important differences are usually a matter of only a few seconds or a fraction of an inch in measurements. If these measurements are not accurate, the test may lead to the wrong conclusion and defeat the purpose of the testing program.

2. *Lineal inches of weld* per pound of electrode can be checked with any measuring rule graduated to $\frac{1}{8}$ in. The number of inches of complete and satisfactory weld per pound of electrode

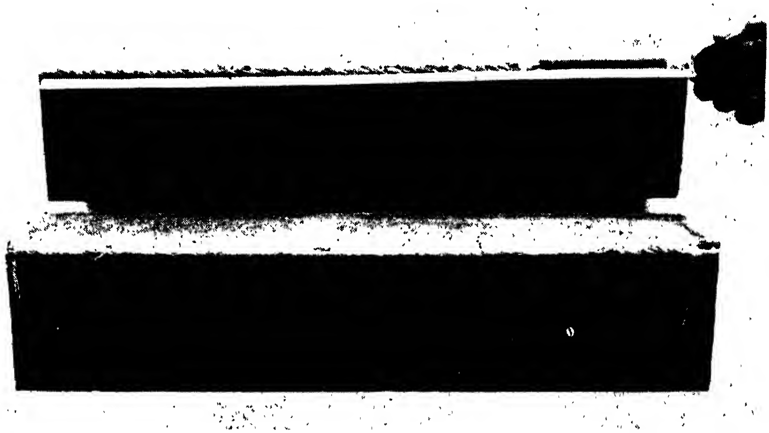


FIG. 190.—The number of inches of satisfactory complete weld of a standard size and form produced per inch of a given electrode is an important element in the test.

is a measurement that should be made on the welds from which the burn-off rate is recorded. It is not unusual to find considerable difference in the number of inches of completed weld per electrode among different kinds of electrodes, as shown in Fig. 190. There are two primary reasons for this.

The first one is that the electrode may deposit a weld that has a tendency to build up a convex deposit, depositing more metal per inch than another having more fluid metal or one fusing more of the parent metal into the joint. An all-purpose type electrode and a strictly down-hand electrode are examples of the extremes.

The second reason is that a greater percentage of some electrodes—both core wire and coating—is actually deposited in the

weld than of some others, either because of differences in the tendency to spatter, or because they differ in the percentage of coating that is reduced to weld metal.

3. *Slag-removal time* is an item of some importance, especially in the deposition of large, multipass welds that are relatively short or in welding deep, narrow groove welds. The comparative length of time required for slag removal under normal conditions for the shop for which the tests are made should be checked with a stop watch or hand watch and calculated in minutes per pound of electrodes burned.

Significance of Burn-off Rate, Lineal Inches of Weld and Slag-removal Time per Pound.—These three items, burn-off rate per pound, lineal inches per pound, and slag-removal time per pound, can all be determined by the use of only a watch and a rule (granting that the test was started with a known number of pounds of sample so that the number of electrodes per pound could be determined) in the course of only two or three hours time on at least two samples of electrodes—for example, a new electrode and the regular one used in the shop.

The comparative rates of burn-off per pound of electrode and the comparative number of lineal inches of complete weld per pound are usually the most important. From these two can be calculated the comparative length of time it takes to deposit a given number of inches of complete weld with a given electrode and the cost of the electrodes required to deposit that length of weld.

From the deposition time, the cost of the labor involved can be calculated. It must be remembered that only actual arc-burning time was timed in the deposition test, but the comparative burn-off time is the important item so far as the electrode differences are concerned. The labor and electrode cost as determined above give a single figure that is entirely comparative except for the cost of electricity consumed in the burning-off process. If there is a marked difference in the figures for different electrodes, the electrode with the lowest figure would be the most economical, everything else being comparable, since the comparative ratio of electric power cost to labor plus electrode cost is small.

An example of such a comparative cost is shown as follows:

Factors involved	Electrode *A*	Electrode *B*
Number of electrodes per lb.	4.5	4.4
Average arc time per electrode	89.5 sec.	90.4 sec.
Inches of standard weld deposited per electrode	19.2 in.	21.9 in.
Total arc time per lb	$(4.5 \times 89.5) = 402.7$ sec.	$(4.4 \times 90.4) = 397.7$ sec.
Total inches of standard weld per lb	$(19.2 \times 4.5) = 85.4$ in.	$(21.9 \times 4.4) = 96.4$ in.
Cost of electrode per lb	\$0.13 per lb.	\$0.13 per lb.
Cost of labor for burn-off per lb. at \$1 per lb	$\left(\frac{402.75}{60 \times 60} \times \$1.00\right) = \$0.112$ per lb.	$\left(\frac{397.7}{60 \times 60} \times \$1.00\right) = \$0.110$ per lb.
Electrode plus labor cost per lb. of purchased electrode	\$0.242 per lb.	\$0.240 per lb.
Cost per inch of weld for electrode and labor	$\left(\frac{\$0.242}{85.4}\right) = \$0.00283$ per in.	$\left(\frac{\$0.240}{96.4}\right) = \$0.00249$ per in.

Percentage difference in cost per inch of weld in favor of electrode *B* = 13.7 per cent.

Interpretation of Differences Shown by Simple Test.—A difference of 13.7 per cent in the actual cost of welds deposited by one electrode as compared with another is significant. Many industries operate on a net profit of less than 13.7 per cent, and where as important and proportionally large an item of expense as electrodes and their actual burning time in the arc-welding process is found to vary so much in cost by the use of two different electrodes, the value of such simple time and measurement tests as this is obvious.

The difference on only 100 lb. of electrodes used between the two electrodes described above amounts to \$3.28. Electrode *B* would deposit 9,640 in. of weld such as was measured in the test at a cost of \$0.00249 per inch, or \$24 for electrode and actual burning time. If electrode *A* were used to deposit 9,640 in. of such a weld, it would cost \$0.00283 per inch, or \$27.28.

These are actually measurable differences between the electrodes on a certain application, and no overhead has been calculated in the cost. This figure does not represent the cost of deposited metal per pound, but does represent the most significant

differences between the cost of applying one electrode to a given job and that of applying another electrode to the same job.

It is significant to note in the above case that if the burn-off rate alone had been considered as the basis of choice and no measurement of inches of welding or number of electrodes per pound had been considered, electrode *A*, the least efficient, would have been chosen. The measurements show however that it actually costs slightly more for labor to burn-off 1 lb. of electrode *A* than of electrode *B*.

Burn-off rate, number of electrodes per pound, and inches of weld deposited by a pound of electrodes are all important parts of the cost picture, and one cannot be considered apart from the other without giving incomplete and probably wrong results. Even the simplest tests must be completed to get truly useful data.

The large factory with a research staff may be equipped with tensile-testing machines and other special testing equipment, but the small shop or factory is not bound by the lack of such equipment to ignorance as to the important properties of the metal in its welds. Sensible observations and simple tests, which can be made in any shop, yield an abundance of important information from which to make choices of electrodes best fitted for that shop's operations.

The above example and discussion covers only the differences between welds made by different electrodes under the same conditions that can accurately be measured by a watch and a measuring rule.

Study of Operating Characteristics of Electrodes.—Actually, these objective tests of measureable variables need not be made until certain other preliminary, but extremely important, observations have been made on the electrode in question.

The first step is to determine whether or not an electrode is suitable for use in the shop from an operating standpoint. A few electrodes burned by an experienced welding operator on some regular production work, or on scrap set up like the regular jobs, will quickly show whether or not the electrodes will function on the machines in that shop without popping out; or whether the electrode will weld the materials in the shop without leaving porosity such as is shown in Fig. 191 or other visible defects that that are not left by the electrode already in use. Preliminary

welding will also show whether there are other operating factors such as excessively foul or voluminous smoke from the arc, predisposition to undercutting, or unfavorable characteristics of slag or molten crater pool, that would require more skill or attention to make comparable welds than with the electrode in use.

If the electrode handles favorably, the next step is to make several welds on scrap metal similar to typical welds that are made on the job, making some with the new electrode and some

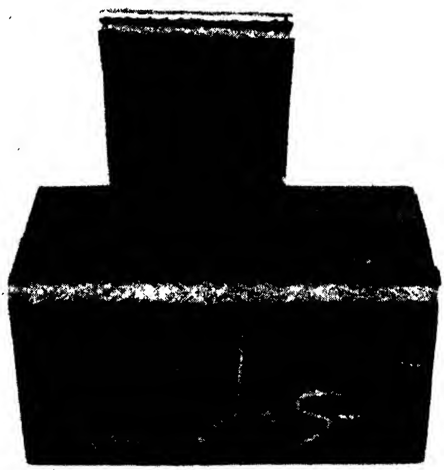


FIG. 191.—Some differences in electrodes become apparent when the deposited joint is examined. Pores such as these show up in their true importance when the joint is broken. Note that the pore goes right through the bead and seriously weakens the joint.

with the one regularly used in the shop. After these welds have had a chance to cool to room temperature, they should be broken and examined. They must not be broken while hot because they will not have assumed the normal crystalline structure that they will assume on cooling, so will not give a true idea of how the weld will compare with the parent metal or how its grain structure will look. For the same reason, they must not be cooled by immersing them in water.

Examination of Preliminary Welds Unbroken and Broken.—Much can be learned by comparing sample welded joints. Figure 192 shows three such welds made by three different

electrodes, one having a noticeably flat, rough bead; one a smooth and well-crowned bead; and one a somewhat rough, overcrowned bead.

Another simple test that gives important information is to saw or cut out with an oxyacetylene cutting torch and grind a cross

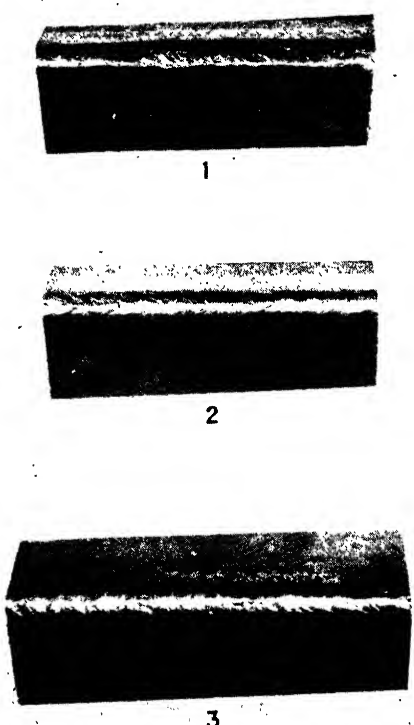


FIG. 192.—Differences in appearance, even where no serious defects such as porosity appear, are important. Note the rough, flat appearance of No. 1, the smooth appearance of No. 2, and the short rippled, convex appearance of No. 3. These are three different electrodes deposited under the same shop conditions on the same job.

section of welded joints, as shown in Fig. 193 (the same welds as Fig. 192). This test indicates the degree of penetration achieved in the weld and also gives a good indication as to the depth of the weld through the throat. An electrode producing welds that are consistently as flat as bead No. 1 are likely to be a source of failure because the throat is already thin, and it is likely that in

case of underwelding (which may happen in almost any shop at some time) the weld would become only a thin shell.

If the sawed and ground cross sections of the weld can be etched with acid, a better idea can be obtained of its penetration, its fusion zone, and any small cracks that may be present in it. Figure 194 shows the ground specimens shown in Fig. 193 after they have been etched in dilute nitric acid (5 per cent in alcohol) for 5 min. Note how the acid etching emphasizes the differences in the welds by showing heat zones, penetration, and bond lines between weld-metal and parent-metal.

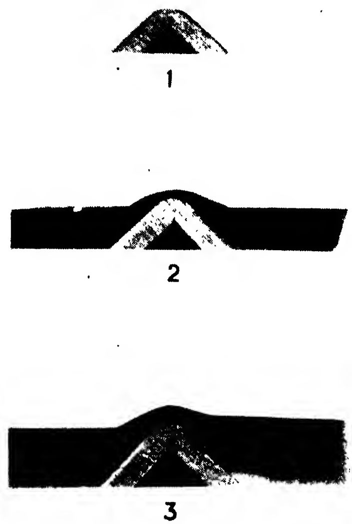


Fig. 193.—The same welds that appear in Fig. 192, as seen from the end after being sawed across the weld. This is an easy way to see and interpret differences. Note the flatness of No. 1 and shallowness of weld metal, the smooth fullness of No. 2, and the overcrowned lopsidedness of No. 3.

The ordinary small welding shop or factory may not have nitric or hydrochloric acid on hand, but a small quantity of ordinary dilute sulphuric acid from a storage battery in a glass or porcelain container will serve to show the outline of the weld metal in a ground cross section of a welded joint. The ground cross section can be immersed in this acid solution and left until the weld-metal outline can be seen, a matter of only a few minutes. It should be understood that this acid and method are not satisfactory for fine weld etching, but they will serve to bring out the outlines of weld metal in a welded joint if no better reagents and equipment are available.

Many things can be learned from breaking such specimens. A sledge hammer, a jack, or a press can be used for the purpose, and should be used in such a way as to make the joint break through the weld if possible. If the weld metal is strong enough to break the parent metal of the joint, it is a favorable indication as long as the joint is not overwelded. If it does not break in the weld, a

partially welded joint should be made and broken. The comparative degree of penetration into the root of the joint and general soundness is evident in a broken weld such as is shown in Fig. 195.

The presence of the gas bubbles and worm holes in No. 1, the smaller number in No. 2, and the relatively few in No. 3 is caused

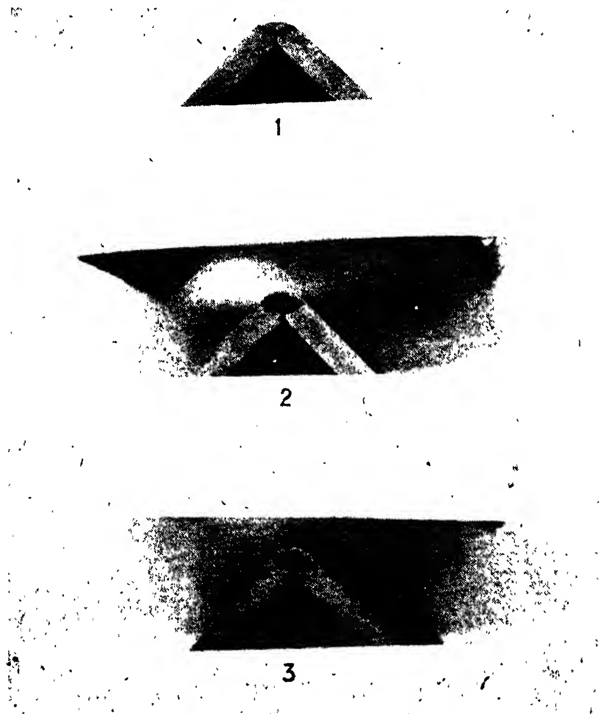


FIG. 194.—The same cross-sectional view of the welds shown in Fig. 193 after grinding smooth and etching 5 min. with 5 per cent nitric acid in alcohol. Note shallow penetration of No. 1, good penetration and balance of No. 2, and good penetration of No. 3.

by differences in the electrodes if the joints and fit-up are the same. There is little question as to which one of these yields the soundest weld on this particular application. Slag inclusions, or a small line of slag at the bottom of the weld, sometimes are found by breaking specimen welds to be associated with one electrode and not with another. Coarse, columnar grain structures, which tend to make brittle, weak welds (No. 3, Fig. 195),

are sometimes found in contrast to welds of fine grain structure, which yield before breaking and tear rather than shatter when specimen welds are broken (No. 2, Fig. 195). These differences are important, since they represent characteristics of electrodes that are being tested for the same purpose under the same conditions.

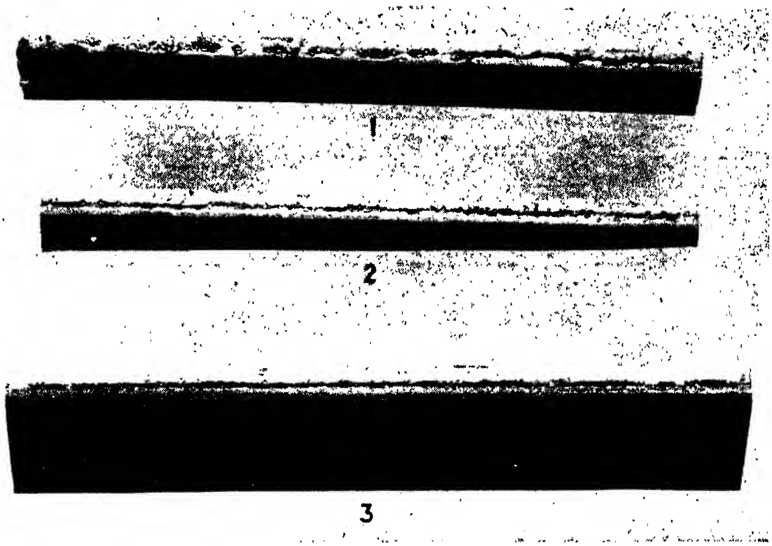


FIG. 195.—The same welds as shown in Figs. 192 to 194 after being broken under a press. Note the serious porosity, thinness, and nonuniformity of No. 1; the jagged break, fine grain, and also the tendency to bubble at the root of No. 2; the grainy, coarse appearance, and slight tendency to bubble at the root of No. 3. This series of observations (Figs. 192 to 195) allow intelligent choice, eliminate much of the guesswork, among the three electrodes.

The information obtained from the preliminary checking of welding electrodes in the manner described causes some of them to be discarded immediately because they are found to be impractical or impossible from the operation standpoint in that particular shop or application.

The objective measurement of burn-off rates, lineal inches of weld per pound, and other tests previously described should follow the preliminary tests on all electrodes that seem to be satisfactory from the operational standpoint and whose economy and efficiency may be more favorable than some others.

Comprehensive Burn-off and Metal-deposition Test.—The simple comparative timing and measuring described is accessible

to any shop since it involves only a watch and a measuring rule. A more complete test can be made if an ammeter and a pair of scales such as shown in Fig. 196 are available. With these additional measuring devices, a more accurate test can be made

FIG. 196.—The measuring devices necessary to make comparative tests justified by the use of more than a few hundred pounds of electrodes. With these tools, accurate measurements can be made that show remarkable differences in total efficiency among electrodes that seem to be "about the same." (*Courtesy of R. G. LeTourneau, Inc.*)

in about the same length of time. Any shop that uses several hundred pounds of electrodes a year would find some sort of an ammeter valuable for checking welding heats and also for use in electrode testing. The scales should have about a 25 lb. capacity and weigh accurately to a quarter of an ounce.

With the stop watch, measuring scale, weighing scales, and ammeter, a comparative test can be made that will give an

accurate evaluation of an electrode, including the following information:

Burn-off rate.

Percentage of electrode actually deposited.

Electricity consumed per pound of deposited metal.

Total cost per pound of deposited metal, including cost of electrode, electricity, and labor (based on burn-off rate).

Number of inches of standard weld per pound of weld metal deposited.

Cost per inch of standard weld deposited by each electrode sample.

Detailed Procedure for Weld-metal Deposition Test.—The test for two electrodes can be completed in about 3 hr., and consists of the following steps:

1. *Preliminary.*—(*a*) Get two plates ⅝ by 7 by 12 or of similar weight and dimension, number them with a steel stamp, and weigh them to ¼ oz. The electrodes will be deposited on these plates.

(*b*) Get 12 representative sample electrodes, weigh eight of them to the nearest ¼ oz., and measure them to the nearest eighth inch. Keep the other four for lineal inches of weld test.

(*c*) Get 12 representative electrodes of stock used in plant regularly, weigh and measure eight as above, and keep the other four for lineal inches of weld test.

2. *Deposition of Metal and Timing of Burn-off.*—Deposit the eight electrodes on the plates, having the same operator use the same welding machine to deposit all the electrodes. An electrode of one type should be deposited on its plate and the plate allowed to remain idle while an electrode of the other type is being deposited on the other plate. A finished plate is shown in Fig. 198. Each bead is slagged before the next bead is deposited beside it, and each electrode is burned down to the same length, 1¼ in. for example, in order to be sure that the same relative length of electrode is burned on both samples. This is important because a small difference in length of butt will make a significant difference in the final result. All butts should be saved and measured; the total length of the eight for each sample should be within ¼ in. of being the same. The arc time is taken with a stop watch for every electrode, starting with the first spark of the arc and stopping with the breaking of the arc at the end of the

electrode. Check with the ammeter and record the arc ampere load for each electrode as it is deposited.

If there is a recording killowatt meter available in the plant, it is desirable to attach it to the power line just ahead of the welding machine and get the total power consumed by machine and electrodes as recorded on the graph shown in Fig. 197. Note that electrode sample No. 2 popped out badly and frequently, thus increasing burn-off time and either requiring more operator attention and skill than No. 1 or leaving inferior welds due to

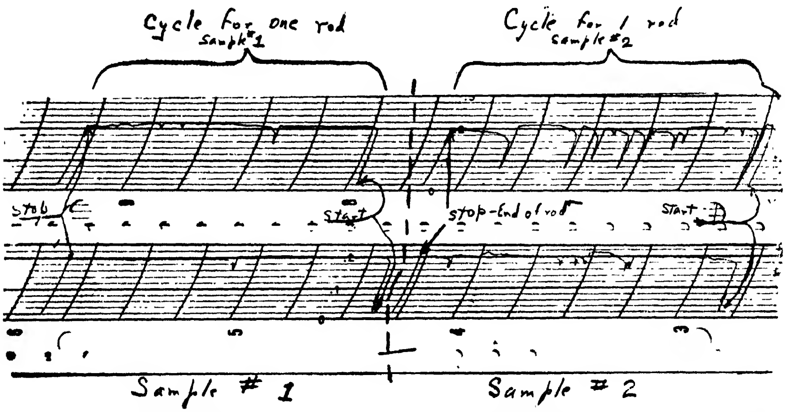


FIG. 197.—For shops that have recording kilowatt meters, the recording of the performance of comparable electrodes is simple. These graphs show that the electrodes of sample No. 2 "popped out" badly and frequently, taking a longer time for the burn off than it should, and of necessity being harder to "handle" than sample No. 1 which burned smoothly and regularly. The automatic recording is impartial. (*Courtesy of R. G. LeTourneau, Inc.*)

breaks in the arc. The recording kilowatt meter leaves an impartial record of power consumption, time, machine-idling power consumption, and electrode performance.

3. *Lineal Inches of Weld.*—Deposit the other four electrodes of each sample on a regular production job, or scrap setup similar to a regular production job, being sure that the fit-up and other elements of the joint are the same and burning all electrodes down to the same length of butt. The operator must deposit the same size of weld with all the electrodes within the limits of a good uniform production job. By recording the total lineal inches of weld produced from four electrodes of each kind under the same conditions on the same kind of joint, a good comparison of lineal inches of weld per pound of electrode can be obtained.

These welds should be a standard weld in the shop or on scrap that can be duplicated at any time in future tests.

4. *Measurements after Deposition.*—Clean all the slag and spatter drops from the test plates on which the eight electrodes were deposited, and weigh each to the nearest quarter ounce. Such a completed and cleaned plate is shown in Fig. 198. The test would have been just as effective if the beads had been

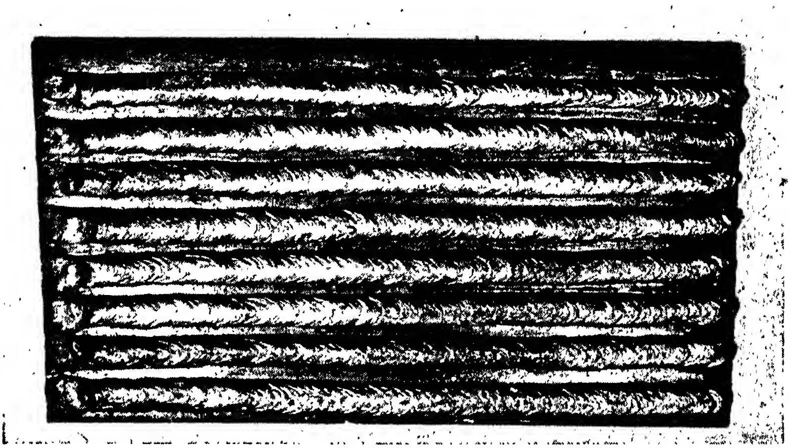


Fig. 198.—A weighed test plate with eight weighed electrodes deposited on it. It has been cleaned of all slag, spatter drops, and other foreign matter and is ready to be reweighed to show how much metal the eight electrodes totalling a certain weight actually deposited.

closer together and shorter. There is no object in crowding the ends of the plate.

Interpreting Deposition Data.—This is the end of the data-gathering part of the tests. The next step is to calculate the costs of electrode, power, and labor from the data of the test and to determine the relative cost per pound of metal deposited and inches of weld per pound of purchased electrode. The data of the test give only arc time, so the deposition cost involving labor is only relative. The cost per pound of electrode deposited derived from these data does not include the operation factor—*i.e.*, the relative amount of time the operator is actually burning electrodes compared with the total time used for a normal job in the shop—and since overhead is usually charged on the basis of labor, no overhead is calculated in the relative deposition costs for the test.

Figures 199 and 200 show examples of the forms used for recording data for these comparative tests and also show an example of the data covering two electrodes actually compared. These two electrodes were both down-hand (American Welding

OPERATOR ________________ TEST NO. ________________

OBSERVER ________________ DATE ________________

ELECTRODE DEPOSITION TEST DATA SHEET

(In this test the electrodes deposited must be burned down to a one inch stub Such an electrode is considered completely burned. The total stubs of each sample of rod deposited must agree with the total of the stubs of the other sample within one fourth inch)

Electrode Number or Name	A	B
Machine used (make—size)	-Transformer	-Transformer
Serial number	1083 B	1083 B
Electrodes, Size and Length	1/4" x 14"	1/4" x 14"
Type	Downhand	Downhand
Number of rods deposited	8	8
Total weight of rods deposited (oz.)	28.8 oz	30.0 oz.
Number of rods per pound	4.40	4.27
Plate (3/8 x 7 x 12") Weight after deposition, cleaned, in ounces.	267.0	264.0
Weight at beginning in oz.	246.7	244.4
Ounces deposited	20.3	19.1
Power open circuit voltage	55	55
Arc volts	34	35
Arc amperes	270	285
Arc time—total seconds	716	748
Labor ($ per hour)	$1.00	$1.00
Power ($ per kilowatt hour)	.025	.025
Electrode ($ per pound)	.13	.13
Lineal inches of standard test weld*—(Total of 4 burned electrodes)	82.75	73.25

* Standard test weld should be a weld which is standard in shop production. Each sample should be welded on a joint which has the same fitup, temperature, plate thickness and the beads should be the same size within regular production limits.

Fig. 199.—Electrode test data sheet with the data from two different electrodes as they were taken during the test in the shop. Note that the differences are all relatively small.

Society E 6020) types of electrode designed for positioned welding or down-hand fillet welding. The price per pound was the same for both, and their general appearance and performance so far as handling characteristics were concerned seemed to be about the same.

The careful measurements of the test brought out some differences which, taken individually, did not seem great, but which, when added together, amounted to a total difference of 16.5 per cent in the efficiency of electrode *A* over electrode *B*.

Calculated by ________________ TEST NO. ________________

Checked by ________________ DATE ________________

ELECTRODE DEPOSITION TEST ANALYSIS SHEET

Electrode Number or Name	A	B
1 Percent of Electrodes Deposited = $\frac{\text{Ounces of sample}}{\text{Ounces deposited}}$	70.5	63.7
2. Pounds deposited per hour = $\frac{225 \times \text{ounces deposited}}{\text{total arc time in seconds}}$	6.38	5.75
3. Inches of standard weld per lb deposited = $\frac{\text{No. of rods/lb.}}{\text{4 rods}} \times \frac{\text{in. deposited by 4 rods}}{\text{\% of rods deposited}}$	129.1	121.3
COMPARATIVE COST PER POUND DEPOSITED		
LABOR = $\frac{\text{\$/hour}}{\text{Pounds deposited/hour}}$	$ 0.157	$ 0.174
POWER = $\frac{\text{Amps} \times \text{volts} \times \text{\$/KWH}}{1000 \times \text{operation efficiency} \times \text{Lbs. Dep./hr.}}$ (use 60%)	0.060	0.072
ELECTRODE = $\frac{\text{\$/lb}}{\text{\% deposited}}$	0.184	0.204
TOTAL COMPARATIVE COST/LB DEPOSITED	0.401	0.450
COMPARATIVE COST PER INCH OF STANDARD WELD DEPOSITED		
$\frac{\text{Cost/lb. deposited metal}}{\text{inches of std weld/lb. of deposited metal}}$	$ 0.003184	$ 0.003710

Difference = .000526 / inch
% Difference = 16.5 %

FIG. 200.—The data analysis sheet for the test shown in Fig. 199. These data analyses define the total differences in the efficiency of compared electrodes.

The difference in the number of lineal inches of a standard weld per unit quantity of electrode was the greatest, and also happened to be the most easily measured. The difference in power looked small, but when it was compared in the light of the percentage of the electrodes deposited (deposition efficiency) it was found to be large. The burn-off rates per electrode varied only slightly between the two samples. The magnitude of such a group of

small differences as shown by the above comparative test of two electrodes from a cost standpoint is really great.

The comparative difference in cost per inch of weld for each electrode looks small (only \$.000526 per in.), but observe the difference in cost and the amount that could be saved by using electrode *A* instead of *B* on the following quantities of *purchased electrode*, based on the amount of weld electrode A will deposit:

Elements of cost	*A*	*B*	Difference saved
Inches of weld per pound of purchased electrode........	91.02	77.27	
(Inches weld pér lb. deposited weld metal × % deposited)			
Cost per inch deposited......	\$ 0.003184	\$ 0.003710	
Cost of 91.02 in. (weld 1 lb. of electrode *A*)..............	0.292	0.338	\$ 0.046
Cost of weld from 100 lb. of purchased electrodes.......	29.20	33.80	4.60
Cost of weld from 1,000 lb. of purchased electrodes.......	292.00	338.00	46.00
Cost of weld from 5,000 lb. of purchased electrodes.......	1,460.00	1,690.00	230.00
Cost of weld from 50,000 lb. of purchased electrodes.....	14,600.00	16,900.00	2,300.00
Cost of weld from 100,000 lb. of purchased electrodes.....	29,200.00	33,800.00	4,600.00

It must be borne in mind that the differences actually measured between these two electrodes look small and can be determined only by tests. The tests are relatively simple and inexpensive. If a comparative saving of \$46 per 1,000 lb. of purchased electrodes can be realized by an afternoon's testing of electrodes, it would be a profitable afternoon's work. Actually, the above figures are not extreme by any means, and greater differences often are found in such tests.

The comparative cost of \$.0401 per pound of deposited metal from electrode *A* against \$0.450 for electrode *B* is not the complete cost of the deposited weld metal. It includes all the variable items of expense that depend on the character of the individual electrode. However, close approximation of the

complete cost of weld metal per pound for a given application can be derived from it.

As an example of how to get such a cost, the comparative cost per pound of weld metal deposited by electrode *A* can be used. The only two items of cost not included in the comparative cost of $0.401 per pound are (1) the cost of labor based on the relative amount of time the operator is actually burning the electrode to the total time he works on the job—set-up, electrode change, etc. (operation efficiency), and (2) overhead, which is usually charged as a percentage of the labor cost. Both of these depend upon the shop or job; neither is entirely dependent on the electrode-deposition process and so neither should be included in comparative electrode tests.

By referring back to Fig. 200, the cost of $0.401 per pound for electrode *A* can be reworked to give a total cost per pound of metal deposited by electrode *A* as follows:

Labor, $0.157 @ 66.7% efficiency	0.235/lb.
Power, same as comparative test	0.060/lb.
Electrode cost, same as comparative test	0.184/lb.
Overhead @ 200% labor	0.470/lb.
Total	0.949/lb.

The most significant relationship between the electrode cost of $0.401 per pound and the total cost per pound of $0.95 per pound is the fact that the labor and overhead (charged on the basis of labor) depends to an extent of 66.7 per cent on the actual burn-off efficiency of the electrode. Any increase in the efficiency of the electrode that reduces the labor item automatically reduces the calculated overhead and labor cost in the total cost per pound of weld metal.

The reason comparative costs are not made to include overhead or operation efficiency is that the real overhead costs vary with machine-retirement costs, supervision costs, taxes, and other such factory costs not related directly to electrode characteristics; and operation efficiency costs depend on fixtures, helpers, etc., which are also items not based entirely on electrode characteristics. The figure of $0.95 per pound of deposited metal does, however, give some indication of the investment a welding establishment has accumulated in a welded joint containing a pound of weld metal.

Special Advantages Gained by Electrode Comparisons.—There are many sources of profit from tests such as those outlined here aside from the important savings that can be realized by reducing costs on the job by using a more efficient electrode.

One great advantage of knowing the comparative cost of one electrode to another on a given application is that it forms a basis for planning improvements in processing and design for greater economy. If, for example, it is found that for the same cost a down-hand type of electrode will give 125 ft. of completed weld on an application and an all-position general-purpose electrode will yield 100 ft., the unit can be examined for the possibilities of making a fixture to position and allow the use of the down-hand electrode. Most important, it gives a basis for calculating relative costs. In this case, a 25 per cent improvement in efficiency of deposition of certain welds could be attained by positioning the work. Twenty-five per cent of the cost of the welding time involved on this particular application, compared with the cost of the fixture, immediately shows the investigator whether or not he can profit by building the fixture and using the down-hand electrode. Often such studies result in considerable savings.

Another common result of such studies involving the comparative costs of weld-metal deposition is that the organization becomes more conscious of the real cost of deposited weld metal and the potential savings involved whenever a unit is redesigned to eliminate even a few inches of welding. It is undeniably true that the arc-welding method of fabrication of a large portion of the machinery and other equipment used for modern living is the most economical from the material, functional, and practical standpoint; but it is equally true that even additional economies can be realized by the redesign of already economical arc-welded units. Such redesign often occurs shortly after the real cost of weld metal, as deposited in an application, is really understood.

Still another result of accurate comparative tests of one electrode with another is that they more clearly define the characteristics of an ideal electrode for a given type of application. Much of the progress made in the development of arc-welding electrodes in the last twenty-five years has been the natural result of someone defining a real problem in welding and someone developing a good product to solve it. Accurate, objective tests

always help to define problems, and what has been true in the field of electrode development in the past is doubtless still true. There are probably no really ideal electrodes for any modern welding application, and one of the most effective ways to get better ones developed is to define exactly what is needed by making comparative tests and finding not only what the best points of each are, but also what they all lack. The tests of today define the problems whose answers are the progress of tomorrow.

CHAPTER XVII

ARC WELDING AND ITS USE BY EQUIPMENT SERVICEMEN

From the beginning of its development, arc welding has been used for repair and maintenance. After some years of development and experimentation which showed that arc welding was practical, some manufacturers began to make new machines by welding the parts together. The advantages of this method of manufacturing equipment were soon evident. Further improvements in the arc-welding process and equipment led to the present-day movement in many fields of industry which makes the arc-welding method one of the most important in the manufacture of machinery and other products fabricated from metals.

Growth of Welding as a Serviceman's Tool.—Because large quantities of various types of machine are being made by arc welding, the use of welding for maintaining, repairing, and servicing such machines has become more important than ever before. There are several reasons for this.

1. Since the machines are made by arc welding, a larger proportion of the material and parts in that machine are made of weldable material. This alone considerably enlarges the use of arc welding for maintenance.

2. The development of better welding machines and a wide variety of electrodes allows the experienced welding-service man to do a wide variety of welding jobs on all types of equipment, whether originally welded or not.

3. The large amount of weldable equipment in the field has brought about the development of portable welding machines especially engineered for such work. An example is shown in Fig. 201. Because there are so many machines to work on and so many applications of welding in the field, the purchase price and maintenance cost of such portable welding machinery as shown in Fig. 201 has become so low that it can be purchased and kept busy most of the time.

4. Public confidence in the welding process as a means of manufacturing and also as a means of repair and service has been developed because it has been proved on the job that welding is satisfactory for such uses. This public confidence makes it possible for skilled arc-welding maintenance men to do much more now than in the earlier days of welding.

5. The speed with which a repair by welding can be accomplished, the confidence with which it is made, and its low cost,

FIG. 201.—Modern portable welding units such as this have been developed to meet the repair and maintenance requirements of large quantities of welded machinery in today's industries. (*Courtesy of R. G. LeTourneau, Inc.*)

either in the field or wherever the job has to be done, are continually winning more and more public reliance for the welding maintenance procedure.

6. The fact that a machine can be almost completely taken apart, reset up, rewelded, altered, or added to by arc welding in the field, under almost any conditions, has made it worth while to many contractors and users of almost any kind of equipment to have a trained welding-service man and the equipment that he needs on the job. There is almost no part on any welded piece of equipment that cannot be cut out and replaced by fabrication in the field, provided the part itself can be made without the use of special machine-shop machinery.

7. The fact that partially worn-out pieces can be built up by padding or can have pieces welded on to them in order to bring them back to their original size and usefulness makes the use of

arc welding in the maintaining of machinery important as a method of conserving expensive materials that are needed to make such parts as rollers, tracks, ground plates, and many other important parts of machines.

The equipment used for a portable arc-welding outfit includes (1) a welding machine mounted in a portable truck, (2) electrodes,

Fig. 202.—Portable welding units like this one, in addition to being mobile, offer weatherproof protection for welding machines and the serviceman's electrodes, tools, accessories, and personal equipment. (*Courtesy of R. G. LeTourneau, Inc.*)

(3) the operator's personal equipment and tools, and (4) an oxyacetylene flame-cutting and heating outfit.

The Portable Welding Machine for Field Maintenance.—An all-round useful portable welding unit should have at least a 200-amp. capacity direct-current welding machine with a good power driving mechanism to operate it up to capacity. It should also have easy adjustments of current and an adjustment to change from straight to reverse polarity with reasonable convenience.

Such a unit has sufficient capacity so that an operator can use $\frac{3}{16}$-in. rod all day and $\frac{7}{32}$-in. rod for short periods of time

without damaging the machine. The fact that it is a direct-current welding machine allows the operator to use a great variety of electrodes and to get a large variety of adjustments to fit the special jobs that he has to do in the field. If he wants to deposit a pad of ordinary weld metal on a special blade, rooter shoe, shovel tooth, or track roller and then use a special hard-facing electrode, he can do it. By using the control for current and polarity, the operator can weld on a wide variety of materials from light-gauge fender material on up to the thickest and heaviest of plates.

If such a unit is mounted in an enclosed body, like the one shown in Fig. 202, it will be more weather worthy and better adapted to field movement, storage of accessories, and general compactness.

Electrodes for Field Maintenance and Service.—Many different types of electrodes may be used with a portable welding outfit, but for the average run of welding and for the average serviceman, it has been found that only a few general types in a variety of sizes of rod are better. For most purposes, only a few types of electrode have any special place in such a portable outfit's stock for the normal variety of field repair jobs. The following are usually minimum requirements:

1. A general-purpose type that can be used in all positions and where the fit is anywhere from perfect to very bad.
2. A special electrode for vertical and overhead welding.
3. A special high-tensile general-purpose rod that can be used for special welds requiring great strength or on unusual steels that seem to require a highly alloyed electrode.
4. A hard-facing rod.
5. A brazing electrode for the arc and usually some brazing rod for gas welding (if the serviceman can gas weld).

If the serviceman knows in advance of some special job where he will do a large amount of welding that he can position for down-hand welding, he should probably get a special supply of down-hand (A.W.S. E 6020 type) electrode before he starts. Such rods are especially adapted to positioned down-hand welding, and to have the special rod will save enough of his time to be well worth while on a good-sized job.

The variety of electrodes in the serviceman's regular supply should include $\frac{1}{8}$-, $\frac{5}{32}$-, $\frac{3}{16}$-, and $\frac{7}{32}$-in. diameter rods for a

machine with the capacity described above. Usually the serviceman should not use a rod with a diameter greater than the thickness of the material that he has to weld. Following this general rule, a welding operator can then choose the largest rod that will penetrate deep into the bottom of the particular joint he is going to weld, or the largest rod he can handle in the position in which he is going to weld the joint. If the weld were flat, he would use $\frac{3}{16}$- or $\frac{7}{32}$-in. rods, whereas if it were vertical or overhead he

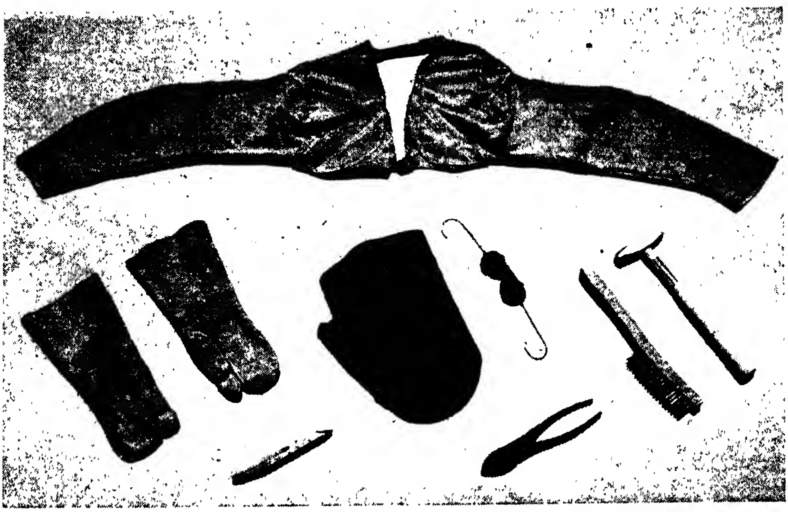


Fig. 203.—The items of personal equipment for safe service welding include the welding helmet, gloves, sleeves, goggles, and the correct dark lens in the welding hood. Slagging hammer, chisel, pliers, and wire brush are essential tools.

might use $\frac{1}{8}$- or $\frac{5}{32}$-in. for the same weld. Most of his work would probably be done with $\frac{5}{32}$- or $\frac{3}{16}$-in. rods.

Personal Equipment for Field Welding.—The personal equipment of the operator should include at least an arc-welding hood, heavy leather arc-welding operator's gloves, a supply of cover glasses for the dark hood lens, leather arm and sleeve protectors (Fig. 203), a weld slagging hammer, a small pointed chisel, and a weld cleaning brush. Usually a heavy pair of pliers, a sledge hammer, a ball-peen hammer, and a cold chisel are included as tools in addition to his ordinary mechanic's tools.

The Oxyacetylene Cutting and Heating Outfit.—An oxyacetylene flame-cutting torch consisting of an oxygen bottle, acetylene

bottle, pressure gauges, length of hose of each bottle, a torch with heating tips and cutting tips, a torch lighter, and cutting goggles are useful pieces of equipment in field service welding. The rear end of the welding truck shown in Fig. 202 has plenty of space for the storage of such a flame-cutting outfit and gives it perfect protection from weather and normal mechanical damage on the job.

This oxyacetylene flame-cutting and heating outfit can be used for preparing jobs for welding by cutting out old welds, veeing out cracks, cutting new pieces to fit in certain repair jobs; for heating and bending parts to the joints; or for preheating certain parts that need to be preheated for proper welding. It may be used for burning oil and paint and other dirt off the area where the welding must be done, in order to get it properly clean. As previously suggested, it may also be used for brazing and gas welding on appropriate jobs. These are only a few of the uses for the cutting and heating outfit on repair jobs in the field.

Materials of Doubtful Weldability in the Field.—From the welding standpoint, there are certain limitations of materials the serviceman can soon determine when he gets on the job. Some of them are as follows:

1. *Cast iron* may be welded by special procedures and certain special electrodes, but for the ordinary arc-welding serviceman, equipped with the ordinary equipment described above, the arc welding of cast iron in many cases is not practical. If the operator has had some experience and training in welding with an oxyacetylene torch, he might braze certain parts of cast iron that are broken, but these almost invariably require a special preheating process and slow cooling process in order to get a good job. It is often more practical for the welding serviceman to look the part over and make a new one from steel, welding it out of standard plates and angles and parts that can be purchased. Such a part redesigned and welded by the serviceman from steel, will almost surely be stronger than the original piece, made from cast iron. Unless replacement parts are easy to get, it will take less time to redesign and weld it than to try to repair it by welding the cast iron.

Not all castings on equipment commonly found in the field are cast iron. Many steel castings are being used in welded machinery today. The operator can easily tell whether a part is a steel

casting or a piece of cast iron, in several ways. (*a*) If the casting itself is welded to the equipment, as shown in Fig. 204, then it is a weldable steel casting and can be repaired in the same way that any piece of welded equipment would ordinarily be repaired by arc welding. (*b*) A cut along the break in the casting with a

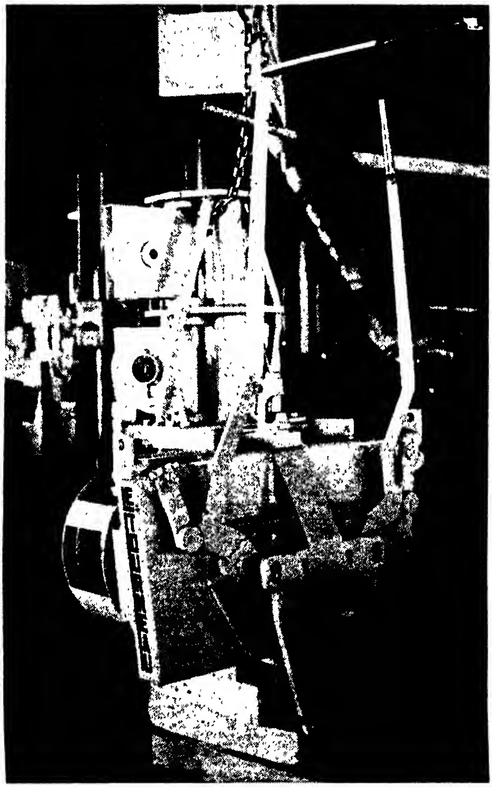


FIG. 204.—By the welds that fasten the cast neck structure (through which the spring passes) to the fabricated main case of this unit, the serviceman can tell that the neck is a weldable steel casting. (*Courtesy of R. G. LeTourneau, Inc.*)

hammer and chisel will usually indicate whether it is a weldable casting or whether it is cast iron. Cast iron will be brittle and have characteristic breaking qualities.

2. *Brass, bronze, pot metal,* and *other nonferrous alloys and copper* cannot always be welded with the equipment described above unless the serviceman is especially skilled in nonferrous

welding. Here again in some cases the experienced operator can use the oxyacetylene welding torch with special rods or certain special arc-welding electrodes and make some repairs, but the average serviceman should be conservative about doing much welding on these materials unless he is sure that he will have reasonable success.

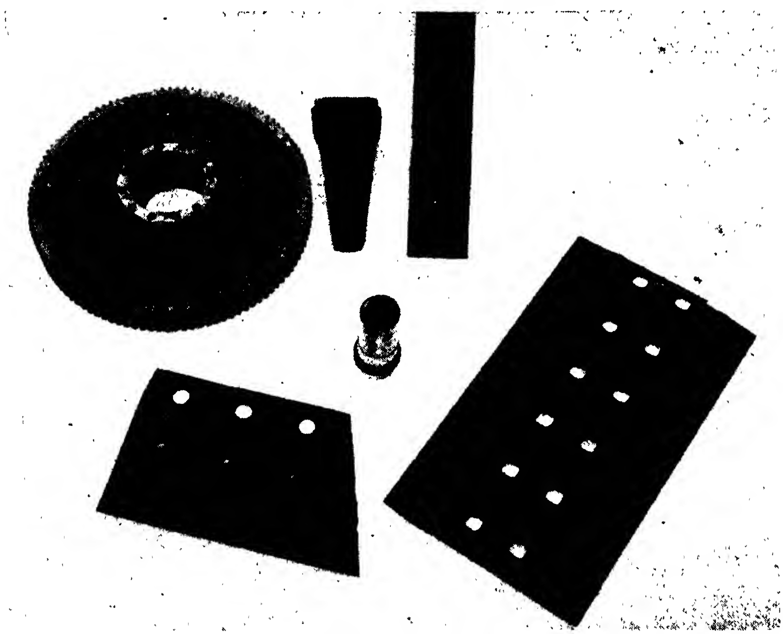


FIG. 205.—Although each of these parts has been hard faced or welded together, none would be readily weldable in the field because each has been heat-treated after welding to give special hardness or strength. (*Courtesy of R. G. LeTourneau, Inc.*)

3. *Tool steels, special high-carbon steels, and other specially alloyed steels* may not be weldable. The serviceman will learn to recognize such steels by the part of the machine they happen to be and what it does, whether they are welded on in the new machine (assuming that anything that has been welded on is weldable and can be welded upon in the field), and often by the type of break that is shown in the part.

How to Determine if a Part Is Weldable.—In general, the question of whether or not a part is weldable may be answered by checking the following questions about the piece:

1. *Has it been welded on before?* If it has, it probably can be welded in the field, if it is not a heat-treated part or special structure such as a cutter blade or gear.

2. *Is it made of a common structural shape* such as angles, channels, plates, I beams, Z beams, or T irons? If it is an ordinary structural member, it probably can be welded on (many

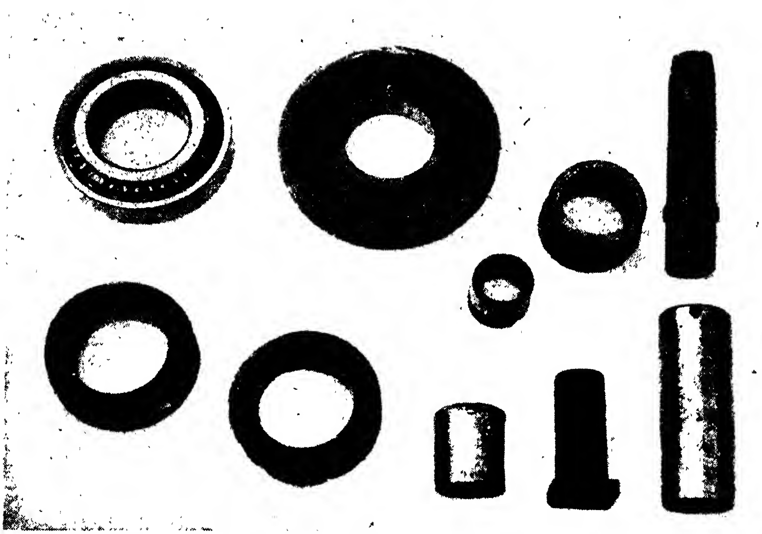


FIG. 206.—Parts such as these hard fast-operating load-carrying parts of a machine should not be welded upon. To weld on them would only stress parts of them and pull them out of shape or weaken them by softening them at the welds. (*Courtesy of R. G. LeTourneau, Inc.*)

riveted structures are made of ordinary structural steel, and they usually can be welded on if they are a part of ordinary heavy machinery).

3. *If it is a casting, has it been welded on?* If it has been welded to some other part of the machinery, it will probably be weldable in the field.

4. *Is the part a special cutting or wearing part,* such as a rooter point, a cutter blade, a bucket tooth, a runner rail, a ground plate, a track roller, or some other part that is likely to have considerable wear on it? If it is, it may be an alloy steel and may or may not be weldable. Parts such as those shown in Fig. 205 all have been welded but would not usually be welded in the field due to their heat-treatment after welding for strength or hardness.

Examination of how the part is made and where it has been fastened on (to see if it has been welded on, or if it has been hard-faced) often shows whether it is weldable. If it has never been welded on before, striking it with a chisel may give some indication as to the hardness. Very hard materials may often be welded, but they *almost always* require special welding procedures, including preheating.

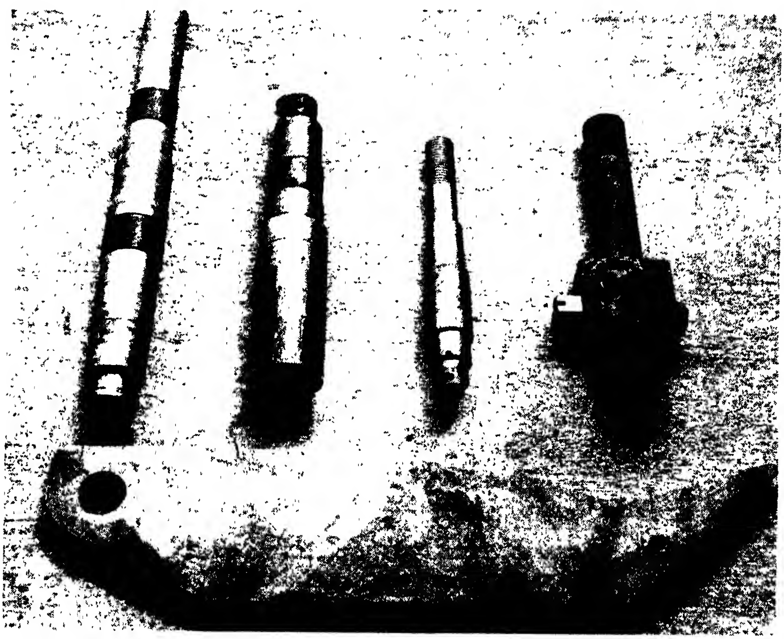


FIG. 207.—Parts such as these carry heavy loads and are usually made of special materials. Often they are specially treated. They should not be welded under any ordinary circumstances. (*Courtesy of R. G. LeTourneau, Inc.*)

5. *Is it a rapidly running part* such as a gear or a shaft with gears on it, and if so is it heat-treated or not? Heat-treated parts may sometimes be built up, but the welding of carburized parts is usually very much like that of tool steel. Ordinarily hardened or fast operating parts, such as sheave wheels and bushings, illustrated in Fig. 206, present difficult welding problems. An attempt may be made to weld them as a method of getting by until the replacement part can be bought; but usually a replacement is a safer practice than an attempt to weld them as a perma-

nent repair. Welding of shafting may sometimes be done by using the best methods of joint preparation, which will be discussed later, and by preheating. *Broken axles should not ordinarily be welded.* The welding usually weakens the adjacent

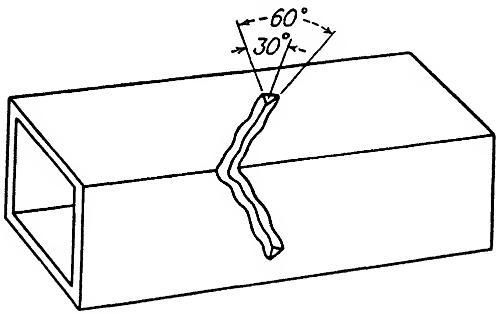


FIG. 208.—Cracks should be veed out right to the bottom and the sides cut at 30-deg. included angle from the crack or 60 deg. total, to ensure weld penetration beyond the bottom of the crack.

area and invites the part to break again in such parts as shown in Fig. 207.

Operations Preparatory to Making Field Repair Welds.—Good welding practice for all weldable material includes the following procedures:

1. *Clean the Part Prior to Welding.*—Before repairing a job by arc welding, all dirt and foreign materials must be cleaned from

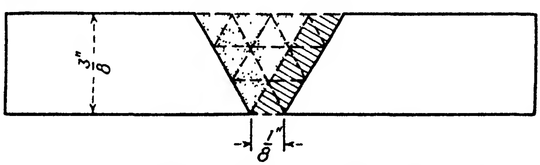


FIG. 209.—Note the increase in volume of weld metal required to make this joint, caused by cutting out ⅛ in. more metal than was required to vee out the crack perfectly.

the joint. The methods of cleaning away dirt of different kinds are various. Oil and paint may sometimes be burned off with the flame-cutting torch; mud, rust, and other foreign materials may be scraped off and brushed off with the weld cleaning brush.

It is important that all oil and grease be removed from the joint before welding in order to remove the carbon and other foreign materials from the place where the welding will be done. If they are not removed, these impurities will be washed into the

weld metal and will keep it from penetrating and fusing into all parts of the joint, thus causing a poor job of welding.

2. *Prepare the Joint Edges.*—The preparation of joints prior to welding should always be done carefully. This involves the veeing out of cracks, as shown in Fig. 208, which may be done with the cutting torch. Great care should be used not to cut out more metal than is necessary because it greatly increases the amount of metal to be deposited. An extra volume, as shown in Fig. 209, increases grain growth and weakens the joint when the

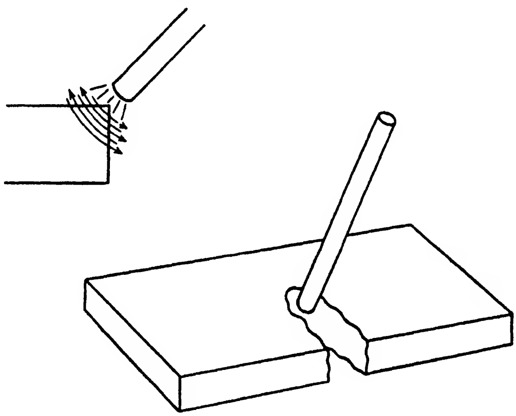


FIG. 210.—A "hot" electrode with the machine set at maximum amperage can be used for cutting steel by using the motion indicated by arrows in the upper left diagram and extending the cut as shown in the larger diagram.

extra welding that is required to fill the gap is done. If a cutting torch is not available, or if only a small amount of cutting must be done, the use of a very hot electrode (the special vertical welding type) with the welding machine set at the highest amperage possible can be used to burn out the edges of the crack so the electrode can be brought right to the bottom of the broken joint. The motion for the electrode for cutting is shown in Fig. 210. This veeing out of a crack assures a completely welded joint. To cover up a crack in a part by welding over it never makes a good repair; the crack will usually creep through the weld, and the piece will be broken again.

3. *Line Up the Parts.*—If the parts have been bent and the structures of the machine twisted because of the broken member, they should be straightened and the parts brought as nearly back to the original position as possible before being welded. This

sometimes involves considerable heating, sometimes with the torch alone, as shown in Fig. 211, and sometimes with the use of jacks, sledge hammer, and other means of straightening the unit. The operating parts of the machine must be brought into alignment during the welding process. It is sometimes necessary, after bringing the parts into alignment, to tack-weld bars of steel

FIG. 211.—Straightening "sprung" members with a torch may often be accomplished by heating, then quickly cooling the area on the outer side of the bend. If the part is badly bent, it may have to be heated in the whole bent area and hammered into shape. (*Courtesy of R. G. LeTourneau, Inc.*)

or angles (or other available bracing material) across the joints in such a way as to leave them open for welding and yet hold the parts in alignment during the process. These parts can be trimmed off afterward when the welding is finished.

4. *Plan Welding to Avoid Distortion.*—The fourth important step before welding is begun is planning to avoid the distortion caused by the heat of welding. Here again, a tacked-on reinforcement to keep the piece from pulling out of shape during welding is sometimes helpful. The operator with a little experience will usually find that the larger the weld, the more pull it will exert, and the more tendency the part will have to warp.

If a weld is all on one side of a member, the pull will tend to shorten that side, causing it to pull toward the weld. On thin

materials, it is often necessary to make short welds, allowing them to cool between the welding processes. This causes the distortion to affect smaller areas of the structure and tends to deform the parts less.

In making large welds, it is sometimes advisable to make small passes and allow cooling between passes, or to make moderately large passes and peen them with a hammer between passes to reduce distortion. This peening or hammering the weld after

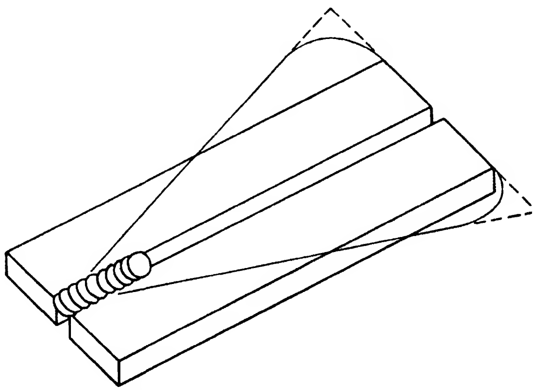


FIG. 212.—This diagram illustrates the increase in distortion with the increase in length of weld deposited continuously (see Fig. 213).

it has been deposited so that it is spread out by the hammering tends to release some of the pull of the weld, and often overcomes some of the distortion caused by big welds.

In welding long welds, it sometimes is best to use the step-back method of welding to minimize distortion. Figure 212 shows the increasing amount of distortion (or pull) of a weld with increasing length. If the parts of the weld are deposited as shown in Fig. 213, by the step-back method, the distortion is decreased, as diagrammatically shown in Fig. 213.

5. *Position the Joint for Best Welding Possible.*—Before actual welding is started, the part to be welded should be placed in the most desirable position for welding and the more comfortable position for the serviceman while he is welding if it is small enough to be adjusted or if the machine it is on can be positioned.

If parts may be positioned so that the welding is straight down into the joints, certain important advantages are gained. (*a*) The welding operator is more likely to be able to penetrate right down

to the root of the weld and get complete fusion of both pieces during the welding process. (*b*) When the weld is finished, it will have a better appearance and will almost always be a better joint because of its smoothness. (*c*) The length of time required for the making of the weld will almost always be shorter because the larger electrode can be used; if the welding job is large, a

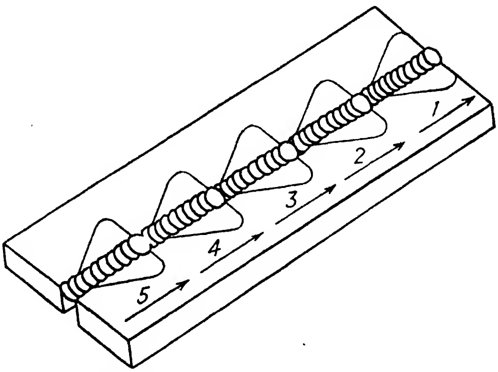


FIG. 213.—By depositing a long weld as shown by the arrows and in the sequence shown by the numbers, the distortion can be minimized as diagrammed here instead of being as great as shown in Fig. 212.

special down-hand electrode, especially designed to give a high-quality weld with fast deposition, can be profitably used.

6. *Select the Right Size and Type of Electrode for the Joint.*—The type of electrode for the job depends upon the fit-up, the position in which it is to be welded, the type of metal, and the other considerations previously outlined in the discussion on electrodes. The diameter of the rod should usually be less than the thickness of the material welded upon. The size of electrode should be decided by the position in which the weld is to be deposited, by the size of the material upon which the weld will be made, and by the width of the joint to be welded. If the joint has been veed out or is a natural V-shaped or T-shaped joint, the largest electrode that will be sure to give complete penetration to the bottom should be used.

7. *Get Electrodes, Tools, etc., within Arm's Reach of Joint.*—The serviceman should always plan the welding of any joint so that he can have his hammer, brush, electrodes, and tools placed within arm's reach of where he is actually welding.

8. *Adjust Welding Machine Properly.*—He should adjust his machine for the type and size of rod that he will use. Table 2 shows general ranges of settings for different sizes and types of electrodes. The specific joint determines just what setting is to be used.

TABLE 2.—SUGGESTED WELDING CURRENT IN AMPERES FOR ORDINARY FIELD WELDING

Size, inches	All-position type electrode for poor fit-up	Overhead and vertical type electrode	Hard-surface type electrode	High-tensile type electrode	Special down-hand type electrode
1/8	100–120	100–120	100–120	100–120	
5/32	120–140	120–140	120–140	120–140	
3/16	140–170	140–170	140–160	140–160	150–180
7/32	170–220	170–220	....	170–220	180–220

FIG. 214.—Note the care with which this serviceman fastened his ground to his work (clamp on the wheel). A firm, well-placed ground ensures better welding. *(Courtesy of R. G. LeTourneau, Inc.)*

9. *Position Welding Machine Ground Positively.*—The ground lead connection from the welding machine should be firmly attached to the unit to be welded, as shown in Fig. 214. Care should be taken to locate it so as to reduce the probable effects

of arc blow. A poor connection will cause slow welding and poor starts on each bead.

10. *Plan His Work so He Is Most Comfortable during Welding.*—The serviceman should adjust his position so that while he is welding he is as comfortable as possible. He will always find that if he can make himself comfortable while doing the welding process his hand will be steadier, he will not get tired so quickly, and he will be able to hold a shorter, faster depositing, smoother arc. He will be able to control the crater of his weld much better. All this makes it possible for him to deposit a better weld in a shorter time.

11. *Preheat if Necessary.*—Another step of good welding procedure on *some* jobs before beginning the actual welding is preheating of the joints. In very cold weather (zero or below zero) if there is any doubt about the weldability of the part, or if there is any doubt about whether it is perfectly clean, one way of making sure that the best job possible is done is to preheat the joint a little. In the case of steels that are known to be weldable, only a hundred degrees or so of heat will be sufficient to make welding start more easily. In the case of medium-carbon steel, such as shafting or special steels that may have a higher carbon content than ordinary structural steel, the joints should be heated to a dull red before welding actually starts. The preheating of any steel for welding allows the heat of the arc to make quicker and deeper fusion at the beginning of the welding process. In some cases, preheating is necessary in order to keep the first few passes of the weld from cracking from the natural shrinkage of the weld.

12. *Start Welding Immediately.*—When the joint has been completely cleaned and prepared for welding (and if necessary preheated), the welding process should start immediately.

Care and Use of Electrodes.—The care of the electrodes that a serviceman uses is an important part of his work. They are one of his most useful tools, and there are certain things that must be remembered and done in caring for them in order to ensure their proper use and operation.

Great care should be taken that the electrodes do not get wet or oily. They will not work if they become very wet. In such cases, they may possibly be dried out, but in so doing they usually lose some of their most necessary qualities.

A new can of electrodes should not be opened until the last of the old can is used. Modern preparation of electrodes by most companies includes a vacuum-sealed can that ensures the right moisture content and freedom from dirt.

Care should be taken to store the electrodes in the service truck in such a way that they do not rattle around and get the coating scuffed, rubbed, or knocked off before they are used. One of

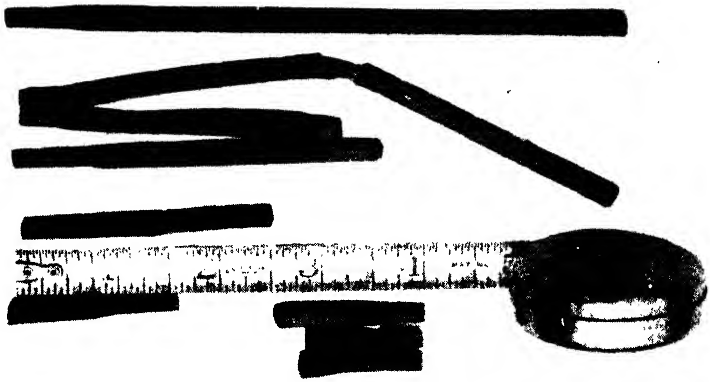


FIG. 215.—The electrode stubs (below the rule) average less than 1½ in. in length, and are properly burned down. Stubs longer than 1½ in. are wasteful. Because bent electrodes cause broken flux and are wasteful or cause defects in the weld, they should not be bent unless it is absolutely necessary.

the best ways to protect the stores of electrodes that are open is the pigeonhole rack, with compartments about the right size to hold the quantity of rod necessary for common use as shown in the service truck illustrated in Fig. 214.

While burning electrodes, it is the best practice in economy and use of time to burn each individual electrode down to a stub approximately 1½ in. long. To throw away a longer electrode stub is a waste of valuable material.

Electrodes should not be bent in their operation, because to bend them abruptly at an angle usually causes the cracking off of the flux, as shown in Fig. 215. This not only results in a slowing up of deposition as the portion around the bend in the electrode is deposited, but also frequently causes pin holes in the weld because of the lack of flux at that point.

It is usually good practice not to stick electrodes together, except where it is necessary in order to get far into an inside weld. To do so reduces the current that passes through the electrode by resistance and makes it more difficult to control the arc because it is farther away. Also, unless the bare part of the electrode has been cut off, it may cause a flaw in the weld where the uncoated part of the electrode joins the other rod.

Special Precautions in Weld Deposition.—The welding done by field servicemen is different from that done in factory production because of the variety of jobs, materials, and conditions involved. Because the serviceman must make his own decisions, often without benefit of engineering control or guidance, certain general weld-deposition factors will be discussed in this and the following section, simply because they constitute good welding practice. In depositing any weld in any position, there are certain things which should always be carefully done. Some of these are as follows:

1. *Clean Each Pass Thoroughly.*—Each pass should be carefully cleaned before placing the next pass on it. This should be done by a hammer and chisel if necessary, followed by careful brushing with the wire brush. It must be complete along the edges of the weld, in order that all the slag is completely removed. The removal of slag is much easier after the weld has cooled; so it is sometimes helpful, if there is more than one weld to be made, to make a single pass on each of them before cleaning the slag from any of them.

2. *Allow to Cool to Below "Blue" Heat before Peening.*—Whenever peening is necessary, it should be done after the cleaning of the slag from the weld, and should not be done while the weld is still hot enough to turn blue from the heat. If welds are peened heavily between temperatures of 400 to 600°F., they may crack (they are in the blue-brittle range of temperature during that time and may be shattered by a hard blow from a hammer).

3. *Make Each Pass the Correct Size.*—The number of passes or weld beads used in a joint is naturally determined by the position in which the joint is deposited, the size of the electrode, and the skill of the operator. Good welding practice requires that on welds that call for more than one pass no pass should be more than $\frac{1}{8}$ in. deep when it is deposited with a $\frac{3}{16}$-in. electrode.

4. *Make the Total Weld the Correct Size.*—The size of weld for most joints should total slightly over the total thickness of the thinnest plate in the joint. Figure 216 shows the correct size of weld for the joint dotted in and also the result when the welds are made twice the size required according to measurement. They actually contain four times as much weld metal as they should and waste much time, electrode, and effort.

Variables in Weld-metal Deposition.—In the actual welding process, there are certain factors that are fundamental to the

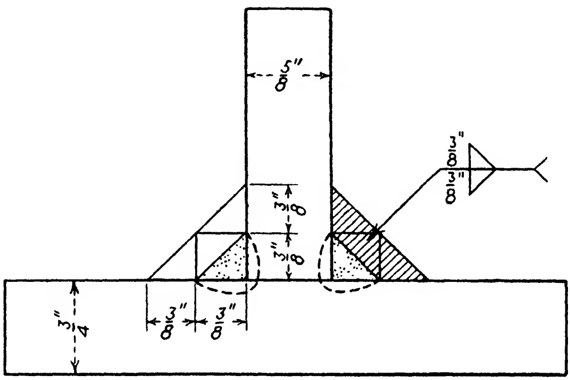


FIG. 216.—Overwelding is expensive. The dotted area shows the correct size of weld, and the shaded area shows a weld twice as large, according to measurement. The overwelded joint required four times the amount of weld as the correct size and is probably weaker because of extra stress and grain growth in the joint and plates.

proper deposition of weld metal. Since they usually have an important bearing upon the quality of the finished weld, some of the most important ones will be discussed, together with how they effect welds.

1. *Arc Length.*—When the proper size of electrode has been chosen and the machine has been set at the correct setting for that electrode, the arc-welding operator then has in his control the deposition of metal by means of the length of arc he uses.

Some freedom can be obtained by changing the adjustment of the machine for various types of welding, but in general, the length of arc should be maintained uniformly at an ideal length that strikes a balance between a long arc giving excessive spatter and a wide bead as shown in *A*, Fig. 217, and on the other extreme, a very short arc that tends to choke the electrode down into

the metal as it is deposited (*B*, Fig. 217) thereby snapping it out, causing the electrode to stick, and forming imperfections in the weld.

2. *Angle of the Electrode.*—In the deposition of welds in any position, the angle at which the electrode is held has much to do with the quality and appearance of the weld.

A

B

C

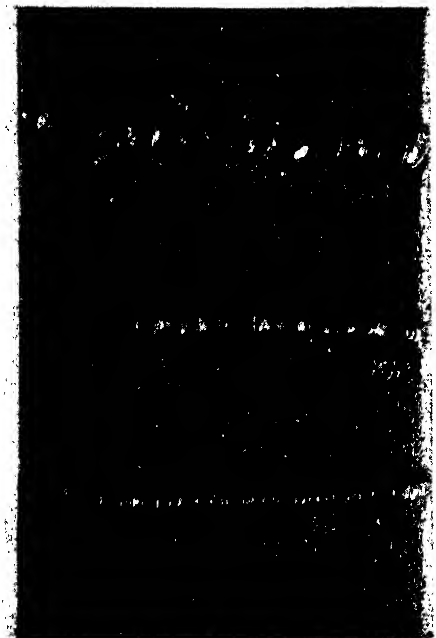


FIG. 217.—Machine setting, angle of electrode, and speed of travel were correct for these welds; but in *A* the length of arc was held too long, in *B* the arc was held too short, and in *C* the arc was held the correct length. Note that *C* is the only satisfactory weld of the three.

If the serviceman bears in mind the need for studying the angle of the electrode to the work and to the direction of travel, he will find that is one of the main factors in the control of the molten metal of the crater of the weld. By changing the angle, the weld metal is deposited on one place more than on another. The degree of penetration onto the plate is controlled to a considerable degree, and the amount of metal deposited in the bead in any one place depends considerably on the angle of the elec-

trode. This varies for different welds, but is an important factor in all of them.

3. *Setting of the Welding Machine.*—The setting of the welding machine is an important factor in the production of good sound welds. As suggested before, the length of the arc tends to give some freedom in machine settings, but for any weld that is

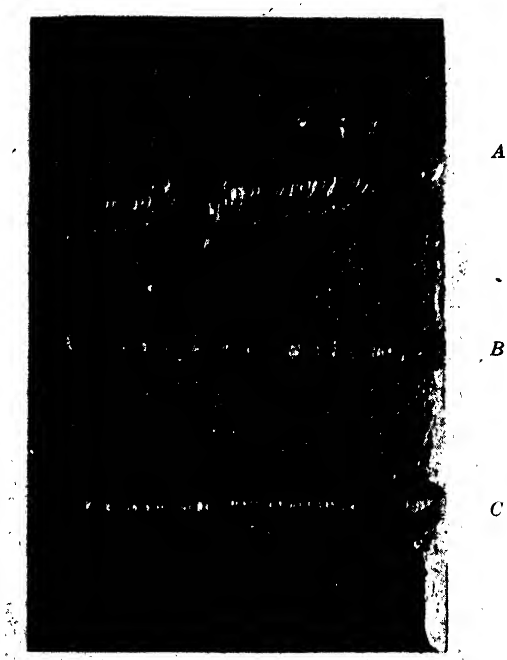


FIG. 218.—Arc length, angle of electrode, and speed of travel were correct for these welds; but in *A* the machine was set too hot, in *B* the machine was set too cold, and in *C* all conditions were right.

made there is a proper setting for the machine within certain reasonable limits.

If the machine is set too hot (too high an amperage) as in *A*, Fig. 218, it is difficult to control the weld, and excessive spatter, unnecessary cutting into the parent metal, and excessive undercutting is likely to be the result. If the machine is too cold, as in *B*, Fig. 218, globs of metal will be deposited in the weld without proper fusion or penetration, and it will be impossible to make either a sound or desirable-appearing weld.

Special Features of Welds Made in Different Positions. 1. *Fillet-type Welds, in Horizontal-fillet Position.*—A large percentage of the welds made are horizontal fillets, where one plate is horizontal and the other vertical to the first. Great care must be taken with this type of weld so that the weld metal is fused deep into the root of the weld and fuses solidly with the vertical plate.

The weld shown in Fig. 221 may look all right from the surface, but a cross section shows that it was a poor weld—because it was not fused in the root. The weld was too large for one pass, and

FIG. 221.—This horizontal-fillet weld may look all right on the surface, but look at the poor fusion in the root. It was too big to make in one pass, so fusion was sacrificed for size. Such a weld is poor and is likely to fail.

it was impossible to penetrate deep enough into the joint in the way in which it was deposited. As with most other welds, the horizontal-fillet weld should be made so that the total weld is greater than the thickness of the thinnest plate in the joint. It should be a little more than half the size of thickness of the plate, such as the weld in Fig. 222, if the plate is welded on both sides.

Horizontal-fillet welds made up of several small beads are much more likely to be completely sound and well fused on the vertical plate than when made in a few large passes.

Great care must be taken in making horizontal-fillet welds not to undercut the vertical plate along the top of the last bead deposited. Figure 223 shows a single-pass weld that is badly undercut. This always weakens the joint and may cause the plate to break along the upper side of the weld. If a welding operator can consistently make first-class sound horizontal-fillet welds, he will have little trouble with other ordinary welds.

2. *Vertical and Semivertical Welds.*—Vertical welds must frequently be made by servicemen in repairing machinery. There are certain things about vertical welds that must be carefully observed in order to make good sound joints.

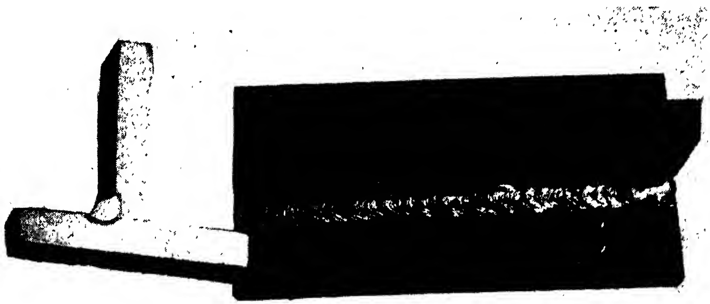


Fig. 222.—This horizontal-fillet weld is well made, well fused, and sound throughout. Note deep throat, lack of undercutting or overlap. With one like it on the other side of the plate, it is the correct size for the joint.

In the first place, it is more important for a vertical weld that the joint be properly veed out and prepared than it is for a flat butt weld where a greater amperage and heat will cause the rod to cut in further and make a sounder weld.

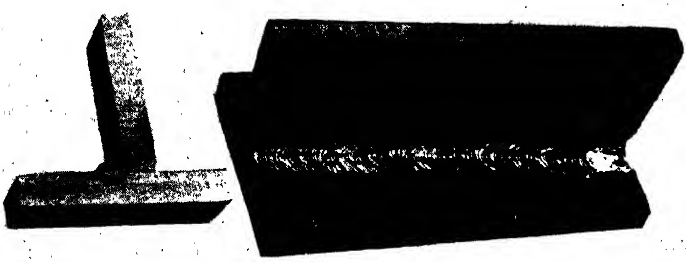


Fig. 223.—This horizontal-fillet weld was deposited with the electrode pointed too directly on the lower plate. Note the undercut at the joining of the weld with the upright plate and the wastefully long leg of the weld on the horizontal plate. The joint is both weak and wasteful.

Vertical welds may be made from the bottom upward, or from the top downward. There are certain advantages to making them either way, but in general if a serviceman wants to be sure that the best possible vertical weld has been deposited (especially

on heavy plates, 3/8 in. thick and thicker) he should start at the bottom and weld upward to the top. It is often helpful to put a small bead in the joint, starting at the top and running down, to seal it shut so that it gives the effect of a perfect fit-up with a slightly rounded corner at the back. The reason for welding from the bottom upward on heavier plate is that if it is properly done the electrode has a chance to burn deep into both plates and into the root of the weld. This gives a more uniform fusion and deposition throughout the whole weld.

FIG. 224.—The center upright weld in this structure was poorly welded from the top down. If the metal had closed over the porous holes still to be seen, it might have been mistakenly passed as a sound weld, but really would have been a weak, porous weld. It should be cut out and rewelded from the bottom upward.

Vertical welds from the top downward make a smoother looking weld, but have some drawbacks. One is that a larger number of thin beads are deposited, and unless the amperage (or heat) is set properly, they may be only partially fused to the bead underneath. A vertical weld deposited from the top downward is more difficult to clean because the slag is thinner and tends to cling more tightly to the bead. Unless the slag is completely removed from these thin passes, a weld may be finished that looks sound, but that if broken open might look as if it had been pasted on.

Figure 224 shows a vertical weld made from the top down (the center upright weld), which illustrates the weakness of such welds if they are poorly made. No amount of welding over this joint will make it a good weld. It will have to be cut out and rewelded —preferably from the bottom up.

3. *Overhead Welds.*—Welds that must be made in the overhead position are usually considered the most difficult ones for a serviceman to deposit. That is one of the reasons why he should plan, in every case where it is possible, to get his machine in a position so that he does not have to make overhead welds.

The actual deposition of an overhead weld is similar to that of a vertical weld or a horizontal fillet; only it is up over the head of the operator and is more difficult to see. Care must be taken to fuse the weld deeply into the root of the weld and to clean each successive pass. Most operators seem to find that it is easier to deposit a weld directly into the bottom of the corner

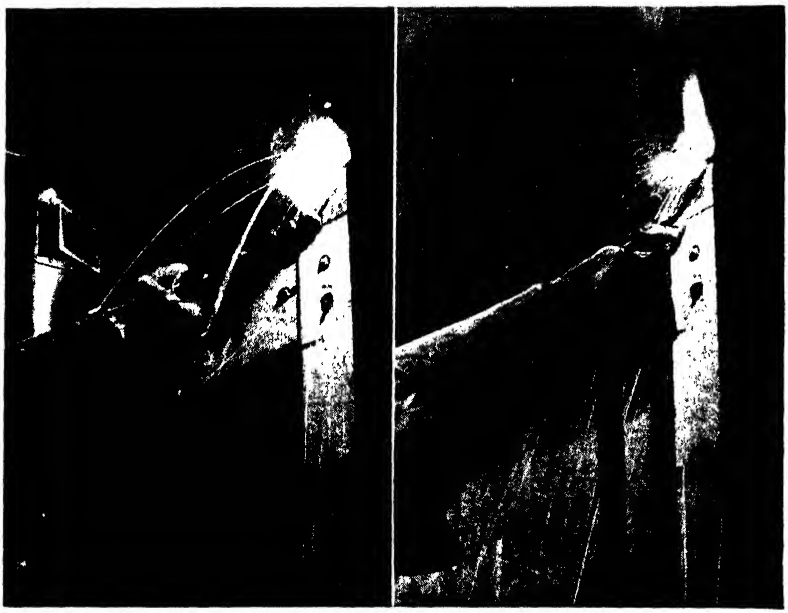


Fig. 225.—The electrode holder, held with palm up as shown on the left, may allow spatter drops to roll into the palm of the welding operator's hand and cause severe burns. If held with the knuckles up, as shown at the right, burns in the palm of hand and between the fingers can be avoided.

in an overhead T-joint weld, and then put the next bead on the horizontal plate, followed by the third bead on the vertical plate, tying the other two together.

One important thing that the serviceman must remember in making overhead welds is always to grasp the electrode holder with his knuckles upward (see Fig. 225) so that the sparks and weld spatter drops that fall from the weld will bounce off his hand instead of down into the palm between his fingers. This avoids painful burns which often get infected.

4. *Horizontal Welds.*—Horizontal welds are much like overhead welds in the problems they make for the serviceman. The

most important thing is to be sure that each successive pass is completely cleaned and completely fused on the upper side to the top plate. The serviceman must also take great care to prevent undercutting the upper plate, as in the case with the horizontal-fillet welds, to keep from weakening the joint.

Bracing and Reinforcing Machinery Structures.—In the repair of welded machinery, it is sometimes necessary or advisable for a serviceman to weld braces to the broken or bent structures of the machine he is repairing.

This part of the serviceman's work is an important one to study carefully before going ahead with the actual work.

Braces and reinforcements should never be put on a structure unless it is definitely failing because of overload or some other field-service cause. No reinforcement should ever be put on a machine just because it looks weak and as if it might fail.

In case a brace or reinforcement is needed, the serviceman should carefully study the way the structure carries the stress while in operation.

In the first place, if braces are to be used, there are certain types of material that should be used and certain types that should not be used. In general, strips, straps, bars, and box sections with caps welded on the ends are the best. Sometimes channels, where both legs of the channel can be welded to the structure so that it forms a boxlike section, serve well, and sometimes I beams can also be used. Ordinarily, angles and T irons are not of any more value for bracing than a strap whose thickness is equal to the part of the angle or T iron that lies flat and is welded flat to the structure. The web that sticks out and is not welded solid does not lend enough more strength than a strap to be worth while.

After having studied the structure that needs reinforcing, the serviceman should plan his bracing so that the braces go parallel or nearly parallel to the load as it is carried on the part of the machine that he is reinforcing. He should never put a brace all the way around a member crosswise with the main load, nor should he put a brace on the main member so that the welds that fasten it to that member go entirely across the structure. In general, braces should always be placed lengthwise with the load of the structure, and the weld should likewise be placed lengthwise, never crosswise.

In welding on braces that do go lengthwise with the member, as shown in Fig. 226, the ends of the braces should never be welded. The welds on the ends are unnecessary from the standpoint of the strength and only tend to weaken the main structure

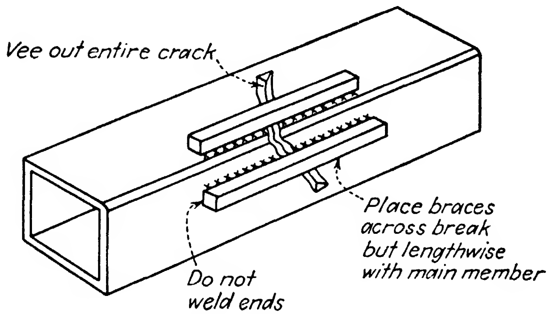


FIG. 226.—This type of reinforcement on structures such as these should be placed lengthwise with the structure and welded on the sides only, never across the ends.

because of the effect of the heat of the weld on the metal of the main structure.

In putting a brace across an angular structure or a curved structure where the brace stiffens the main part of a machine,

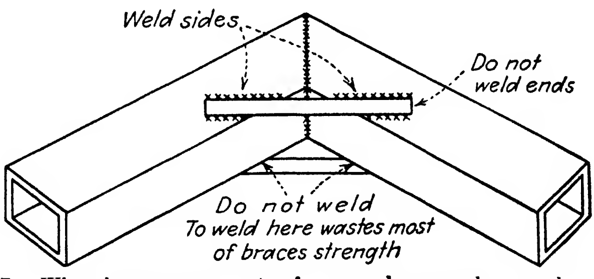


FIG. 227.—When braces span parts of a curved or angular member, the inner "reinforcement-to-member" surface should never be welded. Such welds weaken the reinforcement as well as make the welds on the sides useless.

such as shown in Fig. 227, the ends of the brace never should be welded except in the event that a capped box beam is used for a brace; in that case, only a small weld should be placed at the end of the beam welding the cap to the main structure. The sides of the beam, bar, or reinforcing strap should be welded, but the area toward the inside of the braced structure where the surface of the brace first touches the structure (farthest away from the

outer end of the brace) should never be welded. These inside points, shown in Fig. 227, should never be welded because they throw all the stress of the load the brace or reinforcement should carry on those first two welds and actually serve to cut the brace in two. If the inside welds are made, all the welding on the rest of the brace is worthless.

Concluding the subject of bracing, it should again be said (1) that bracing should not be done unless it is absolutely necessary; (2) that braces should never run crosswise with the main load or all around a structure, but always lengthwise; (3) that, in general, the ends of braces running parallel with the main load on a structure should never be welded.

CHAPTER XVIII

SOURCES OF INFORMATION ON WELDING PROBLEMS

The resourcefulness with which a man who is trying to solve a problem gathers and uses the available information on related subjects has much to do with his success in its solution. This is as true of the solution of welding problems and the development of welding applications as it is in any other field of endeavor.

Much of the rapid progress of welding during the past few years must, of course, be attributed to the resourcefulness and ingenuity of the mechanics, designers, engineers, and production men who have applied the fundamentals of the process to their individual problems in their own specialized way.

It should always be borne in mind, however, that genius cannot function unless it has at its command the fundamentals of the processes or activities in which it is expressed. It is absolutely necessary for a certain amount of fundamental information and education to be made available to members of an organization or to individuals who are working with welding problems before they can visualize their own limitations and the possibilities of the use of welding as a solution to them.

Scope of Available Welding Information.—Between the time when the commercial use of arc welding was begun and the present, a large amount of information has been gathered and organized upon many phases of the subject.

Much of this information is recorded in the literature available to the student of arc welding or the organization that is developing arc-welding production in its own place. Much unwritten information may be gleaned by the proper approach to available sources.

In general, there is a large amount of good elementary information available that may be used in the training of welding operators in the fundamentals of arc welding. This same general information serves well for some of the elementary training of other members of welding organizations since it deals with fundamental equipment, applications, and operations in welding. For

the most part, this information is generalized and elementary and tends to lend itself to the training of operators.

On the other hand, there is a large amount of highly specialized research data on a wide variety of subjects including processes, materials, equipment, and certain aspects of design. These data are available from several sources. Much of this information is highly specialized and naturally requires some knowledge of arc welding for its interpretation.

It is this fundamental research on specialized aspects of arc welding, however, that leads to the refinement and the final development of its applications. Its resourceful use will lead to the solution of many individual problems that will arise in welding organizations in the future. Such sources of fundamental research data must be kept in mind and must be interpreted in the light of their specific applications.

Lying between the extremes of the elementary information, on one hand, and the highly specialized research literature, on the other, is a somewhat generalized "popular knowledge of the trade" that is covered largely by trade journals. Their articles reflect the current developments within the industry and usually deal with the major problems of equipment, "know-how," trends in applications, and of new developments in the industry.

A discussion of the sources of information and the means of keeping up to date with the welding industry will be offered in the following sections.

The American Welding Society's Literature and Services.—The American Welding Society is a technical organization whose objectives are the advance of the art and science of welding by supporting and conducting individual research; by making available literature covering all phases of welding; by promoting the cooperative exchange of ideas of specialists in the field of welding by means of national, regional, and local meetings of its members and others interested in the field; and by establishing codes and standards for the important aspects of activities or products associated with welding.

The Welding Handbook is published as an official compendium of information covering all the technical aspects of welding that have been described and are currently considered by the specialists and leaders of the American Welding Society to be fundamental to the growth and development of arc welding. This

handbook is edited and revised periodically to include the results of new research and further to refine the existing information.

The Welding Journal is the official technical journal of the Welding Society and is published monthly for the members of the society.

It includes feature articles which are usually papers presented by the special speakers at local or national meetings of its membership, authoritatively written and usually illustrated. A report of the activities of the National Society and local sections is included; and periodically a roster of the entire membership is published. It also includes a section in which the results of welding research are reviewed.

Another helpful feature is a section devoted to current literature on welding, in which articles, lectures, or reports printed in other publications are reviewed or at least names of authors, titles, and the publications that carried the articles are given.

The journal also carries advertising of the suppliers of welding equipment and all the accessory materials, processes, services, and accessories to the welding industry.

Welding codes and specifications that have been carefully built up by specialists in the American Welding Society are another source of information the society makes available to those interested. Lists of these codes and standards and specifications may be secured from the American Welding Society, whose headquarters are at 33 West 39th Street, New York 18, New York, or through any member of the welding society. The codes, standards, specifications, and special bulletins may be purchased singly or as a bound group by whoever has a need for them.

A few examples of the standards, codes, and specifications are "Tentative Specifications for Iron and Steel Gas Welding Rod," "Code for Minimum Requirements for Instruction of Welding Operators," "Rules for Fusion Welding Steam, Oil or Air Piping in Marine Construction," "Recommended Procedure to Be Followed in Preparing for Welding or Cutting Certain Types of Containers Which Have Held Combustibles," "Inspection Methods Used in Manufacture of U-69 and U-70 Pressure Vessels," "Report of Committee on Welded Rail Joints," "Standard Methods for Mechanical Testing of Welds," "Codes for Arc and Gas Welding in Building Construction," and "Specifications for Welding Highways and Railway Bridges."

These are only a few examples of the special welding codes, standards, specifications, committee reports, and articles that are available through the American Welding Society.

The national annual meeting of the welding society usually is held in conjunction with the Metals Congress, which is a meeting of several national technical societies held in some large, centrally located city in which meeting places are available for the technical sessions and meetings; and also where equipment, materials, supplies, and almost all other phases of the merchandising and activities connected with the industry may be displayed by their manufacturers.

This cooperative undertaking provides a splendid opportunity for a review of technical advancements throughout the year and for developing the acquaintance of leaders in the industry. It makes it possible to see the new developments in machinery, processes, or supplies (often in action) accompanied by the engineers who developed them and who may best advise their application.

Attendance at such a conference, including both attendance at technical meetings for the reading of technical papers and observation of the displays and an exchange of ideas with others in the industry, can provide a helpful and important means of keeping informed as to the developments and trends in the field.

Local sectional meetings open to the membership and usually open to all others in the community interested in welding or allied problems, held in communities where an active section of the American Welding Society is functioning, form a medium by which the members and others may exchange their ideas and listen to guest speakers who are specialists in their field of welding. They form an important means of local exchange of ideas and cooperation in the advancement of welding development.

The speakers for meetings of this type are usually specialists in welding construction, inspection, design, engineering, control, special allied processes, and developments resulting from special research or men with years of practical experience in some phase of the industry. They are usually connected with some welding organization that is progressive or outstanding in the industry. Their services are almost always rendered free of charge to the local section they visit and address as a means of further cooperatively advancing the welding industry.

Active participation by members and others interested in such meetings form an important source of information. Meeting these specialists and questioning them on subjects of mutual interest at sectional meetings or on the scene of work, when such men are invited to visit local manufacturing plants, may prove very valuable as a medium of exchange of ideas and mutual advancement in techniques.

Membership and its contact with the local and national leaders and development in the welding field provides a ready medium of information and approach to a means of assistance on almost any welding problem. Since the objectives of the society are educational, membership is not highly exclusive or rigidly restricted.

A letter of inquiry addressed to the American Welding Society may almost always be expected to result in some suggestive assistance on almost any welding problem. Information on membership and participation in the welding society is readily available.

Other National Technical Societies.—There are other nation-wide technical engineering societies which, because of the nature of their activities, have certain information and contact with welding.

A few of these associations, institutes, or organizations are as follows:

American Society of Mechanical Engineers.
American Society for Metals.
American Institute of Steel Construction.
American Petroleum Institute.
American Waterworks Association.
American Boiler Manufacturers & Affiliated Industries.
American Institute of Electrical Engineers.
Society of Automotive Engineers.
Heating, Piping and Air Conditioning National Contractors Association.
National Electric Manufacturers Association.
The Edison Electric Institute.
Steel Plate Fabricators Association.
International Acetylene Association.
American Society for Architects.

Corresponding to the American Welding Society, there are technical societies in England, Australia, and other parts of the

world that serve the same general function the American Welding Society serves for the United States. One means of getting in touch with such organizations, if a special inquiry is to be directed or a special study made of welding in foreign countries, is to inquire of the American Welding Society the names and addresses of such organizations.

The foregoing list probably includes the major national societies that would be interested in welding and that would have information about it because of their connection with the industry. It may not be 100 per cent complete, but it is a suggested source of possible specialized information on welding that might be approached from the specific angle associated with the name of each organization.

United States Government Agencies.—Because of the use of arc welding in the production of so much equipment used by the Army and the Navy and other government agencies, there have been codes of inspection and development of design and other welding information accumulated by certain of these agencies. For the most part, this information is not generally available (nor is it of particular significance) to most of the public, but it is mentioned here because it is highly developed and significant to people who weld products to these agencies' specifications. The National Research Council is an exception, as explained later.

The American Bureau of Shipping has, for example, certain specifications and codes covering welding materials, designs, electrodes, and welding inspection.

The Bureau of Ships in the Navy Department also has similar technical data and information that, for the most part, is highly specialized and somewhat restricted but is significant to manufacturers who are doing work for the Navy or who are interested in their welding standards. The same is generally true of the Bureau of Yards and Docks in the Navy Department.

The United States Coast Guard, especially its Office of Marine Inspection, also has inspection standards that are significant to manufacturers or contractors who have contracts with that agency.

The United States Army Ordnance and the *United States Corps of Army Engineers,* because of the use of large quantities of welded equipment, have certain codes, designs, standards, and practices that are significant to manufacturers, operators, or suppliers who

are engaged in work or will be engaged in work with these departments. In this case again, the information is frequently of a restricted nature, but is available to those people who are closely associated with the work.

The National Research Council is another organization that has operated under the War Metallurgy Committee during the war period on fundamental research in welding. The future of this organization is not known, but it has rendered, and continues to render, a tremendously important correlatory and directional effect on current welding research.

Many of the data they have developed by their research program are of a restricted nature as long as such restrictions are necessary for military reasons during this war, but will provide an important contribution to welding literature at such time as military restrictions can be removed and the results of this research can be made available through the American Welding Society and other channels.

The projects that they have undertaken have been wide in variety and scope. Some are extremely specialized, and others have been of a fundamental nature, almost bordering on "pure research." The results of the coordinated and cooperative research carried out under this program have been almost phenomenally productive in practical and usable results that have already greatly affected many phases of the welding industry.

At the present time, this information is available to those who are engaged in welding products for the Armed Services within certain classifications that can be determined by their local government inspectors or the military officers in charge of the district in which their production operations are performed.

Major Public Liability Insurance Agencies.—Another group of agencies that have highly specialized classifications and standards for certain types of welded structures and have codes, information on procedures, processes, materials, and operations are the major insurance agencies that insure and inspect certain structures involving public liability.

Examples of such organizations are the following:

Hartford Steam Boiler Inspection & Insurance Company.

Associated Factory Mutual Fire Insurance Company.

National Bureau of Casualty and Surety Underwriters.

National Board of Boiler and Pressure Vessel Inspectors.

National Board of Fire Underwriters.

This list is by no means complete, but it is suggestive of the type of organization that has a special interest in the inspection and control of procedures for welding. These organizations have trained technical men who are well-informed on certain phases of arc-welded construction and arc-welding inspection and are significant sources of information and control for people who are working on the type of job they certify, insure, and inspect.

Trade Journals and Periodicals.—The trade journals that are published weekly, biweekly, or monthly, some specifically for the welding industry and others for the metal-working industries or for the general manufacturing industries, are an important source of information on arc welding and welding problems.

One of the most important parts of their service is the fact that their technical editors are trained observers, mindful of the trends, developments, and advances in the industry, and feature articles that present those developments and trends in a semi-popular, well-illustrated style.

These periodicals come at regular intervals and therefore are a continuous service that provides a source of up-to-date information in small sections that may be examined and read in a relatively short while, rather than by a period of laborious study of a large compendium of information.

Almost all these journals carry a considerable amount of advertising of the materials, equipment, service organizations, processing machinery, suppliers, and others associated with the industry. These advertisements alone frequently furnish a good index of development or progress; and, because they are well-illustrated and are calculated to have "eye" appeal, they give the student of welding or the member of a welding organization who has problems in mind or who is trying to keep up-to-date on the subject a regular and relatively easy means of keeping track of what is going on.

A further service most of these journals maintain is a listing of current literature, sometimes of current inventions, and sometimes of the recent patents within the field to which they are devoted.

Some examples of the leading trade magazines that fall within the group just discussed are:

The Welding Engineer.
The Iron Age.
Steel.
Industry and Welding.
Factory Management and Maintenance.
Mill and Factory.
The American Machinist.
Machinery.
Metals and Alloys.

This list does not include all such publications, but does include many of the foremost trade magazines that feature articles and equipment involving welding.

Libraries, Public and Private.—It is surprising to many students of welding to find the amount of information that even a relatively small public library or school library can present upon the subject.

Almost all public libraries have a card index with cross-references that cover the subject of welding. Most of them have copies of the older, better known, and commonly accepted textbooks on welding covering such phases as design, training of operators, and applications; as well as the newly published texts of which there are several. Many of the larger libraries also have complete files of some of the leading trade magazines that cover welding which may be examined in the library or even sometimes taken out and studied elsewhere.

By consulting a library, the more or less stabilized literature that has been published in book form upon any phase of welding can almost always be examined, often with considerable profit to the man who has a welding problem.

There is a movement developing among some of the large universities which is resulting in the building of special welding-information libraries. One notable example is the A. F. Davis Welding Library in the university library of the Ohio State University. This library is making a special attempt to gather together all welding information possible, including patent literature covering welded structures or involving welding.

As the literature of this relatively new industry becomes more stabilized, more complete, and more mature, there will be a greater tendency toward well-rounded and complete libraries covering its problems.

Engineering Services of Suppliers cf Welding Materials and Equipment.—One mark of the technological and scientific development of our modern civilization is the growth of the engineering services that are supplied by the manufacturers of materials or equipment involved in production of goods for modern use.

This is just as true in the production of equipment, materials, and services in the welding industry as in any other. As a matter of fact, much of the task of public education which has led to the great development of the industry is the result of the services and educational activities of some of the manufacturers of welding materials and equipment.

To the suppliers of the manufacturing equipment or the processing equipment used in the welding industry falls a large portion of the education of the beginners in the "know-how" of the use of the machinery and the processes of the industry.

Because they have sales engineers who are essentially servicemen, and who can go between the factory that designed and built the equipment and the organization that is using it, they form a force of helpful technical educators. Naturally they are merchandisers whose loyalty and vested interests may be centered most closely around their company's product, and their services must be recognized as having a legitimate bias.

Most of the organizations that produce electrodes, flame-cutting equipment, welding machines, or other accessories to the welding industry are continually trying to improve and develop their product. As each new improvement is made, they pass it along to industry and thereby help to keep organizations up to date on the developments in the industry.

Many of the leading manufacturers of welding machines or electrodes have special schools in which they train operators and in which they hold special training programs for welding designers or engineers.

Almost all have literature on the training of operators, some having well-organized books on operator training and on the use of their product. Several leading suppliers of equipment or materials publish private news and technical bulletins in which they announce their new developments and show applications of their products. These are essentially merchandising mediums and contain much fundamentally sound data as the basis for their special purpose.

It is not uncommon for beginning students of welding to be able to get large amounts of fundamentally good information from such organizations; and it is a common occurrence for people who are already in the welding manufacturing industry to turn to the suppliers of their machinery, equipment, and materials for further information or to help them solve problems arising in their operations.

There is much room in the industry for further improvement of this type of service, especially among the suppliers of steel with regard to the weldability and the possibilities of ease of, or improvement in, processing of their product. Large steps have been taken in this direction in the past few years, and probably much greater ones will be made in the years to come.

The appearance of several high-grade moving pictures on welding techniques, welding processes, welding methods, weldability of steel, aluminum, and other metals, and other aspects of welding is another splendid and important educational function that industrial suppliers are just beginning to exploit.

Information on Arc-welding Design.—One of the most important considerations in the arc-welding industry is that of design.

Because the industry is relatively new, there has been a tremendous amount of experimenting and transitional growth in the thinking of designers for the use of arc welding to its greatest efficiency, and many of the elements of arc-welding design are not described completely or organized in readily available literature.

There are several textbooks on arc-welding design and several others that include references to design by giving careful studies of arc-welding applications. The examination of the lists of leading books on welding presented by the American Welding Society shows several dealing with design. Most deal with fundamentals; and the application of those fundamentals must be absorbed, translated, and applied to the product an organization proposes to weld.

The "Welding Handbook" includes certain information on welding design and welding metallurgy.

Two series of study of the applications of welding have been published by the James F. Lincoln Arc Welding Foundation in Cleveland, Ohio, each of which includes a large variety of arc-welded applications together with the intimate details of their

design, fabrication, cost, processing, and special advantages accruing because of arc welding. The later one, "Studies in Arc Welding," was published in 1942, the earlier one in 1938.

There are several specialized books coming on the market that deal in varying degrees with design of arc-welded structures in special fields, such as shipbuilding or welding aircraft. Much remains yet to be done in the development of complete and well-organized welding design data, but enough has been done in that direction so that conversions to welding from other methods of fabrication are common. The creation of new machines of welded construction soon follows in most cases. Arc-welding design is a mode of thinking that requires development and experimental practice on the part of designers, engineers, and draftsmen.

Special Consultants.—For certain specialized problems in arc-welding practice and design, there are welding consultants who are available as professional consulting engineers and who may be contacted through regular commercial engineering consulting organizations.

Such men usually have had a good background of welding training and are adept at approaching the problems of welding from an elemental standpoint and visualizing the possible solutions within a given situation.

This is essentially what is done in solving any problem in welding. By the proper use of all the available information, together with a certain amount of technological imagination, most problems can be solved. Sometimes special consultants can help to solve problems that look complicated to those who are working close to them because of their past experience in analyzing such situations and because they are unhampered by the background of thought and experience that has made the problems difficult for those who are trying to solve them.

INDEX